SECTION 530.00 – PAVEMENT REHABILITATION DESIGN

The procedures described herein are accepted methods to design a wide range of pavement rehabilitation alternatives. Pavement rehabilitation is needed to extend the life of a pavement structure by treating structural deficiencies, roughness or environmentally induced deficiencies such as thermal cracking. Rehabilitation is needed periodically on otherwise adequately designed pavements due to increased traffic, excessive thermal cracking and surface deficiencies such as stripping, raveling, joint faulting, rutting and roughness. Badly fatigued (alligator cracked) pavements may be more economical to reconstruct.

All pavement rehabilitation strategies should include an investigation of the existing pavement condition. High priority should be given to recycling existing pavement materials. The following is a listing of the pavement rehabilitation strategies which have been applied in Idaho or are common in the western states:

- Overlay: Flexible overlay over flexible or rigid pavement or over cracked and seated, break and seat and rubblized rigid pavement, and "white topping" i.e., unbonded rigid overlay of flexible or rigid pavement.
- Mill and Inlay: Removing and replacing a portion of the roadway surface course.
- Full Depth Reclamation: Pulverizing the existing plant mix surface which may include a portion of the aggregate base, mixing with a small amount of cement, emulsion or lime and relaying the material as a base, with placement of a new surface course. CRABS (Cement Recycled Aggregate Base Stabilization) is the most commonly used full-depth reclamation alternative.
- In-place Recycling: Hot in-place recycling includes heating, milling to a depth of 2 to 3 in. (50 to 75 mm) and relaying existing asphaltic concrete as a rejuvenated surface. Deficiencies in gradation and/or asphalt content can be corrected by the addition of aggregate and asphalt.

Cold-In-Place Recycling involves cold milling, pulverizing and relaying existing asphalt surfacing with the addition of hydrated lime and a rejuvenating agent or emulsified asphalt. Except for low volume roads, cold-in-place recycled pavements will need a high type plant mix surface. A seal coat is needed as a minimum to reduce raveling.

530.00.01 History of Pavement Rehabilitation in Idaho From the time of initial construction of the state system until the early 1990's, the predominant method of pavement rehabilitation was to place a plantmix overlay on the existing pavement. A relatively small number of Cold In Place Recycle (CIR) projects have been constructed beginning in approximately the mid-1980's. Subsequent to the early 90's, the predominant method of pavement rehabilitation has been Cement Recycled Asphalt Base Stablization (Crabs) followed by a plantmix overlay. While usage of plantmix overlays without treating the existing pavement has remained significant, at this time Crabs is the most widely used method for major rehabilitation of existing pavement in Idaho.

Initial construction of the state system for the most part included adequate base materials for providing a long lasting pavement. Some roadways, however, were constructed with marginal or thin base materials. Geotextiles were not used in Idaho until about the mid-1990's. Over time, the aggregate base layers of many roadways became contaminated with fine particles from the underlying soils. This contamination reduces the stability of the base materials and inhibits drainage. With the primary method of pavement rehabilitation being a plantmix overlay, many State and NHS highways consisted of a thick asphalt layer (up to 1 foot) on poor base materials as of the early 1990's.

Asphalt pavement is often referred to in engineering terms as flexible pavement. This is because the pavement is intended to flex under loads and with varying temperatures. However, the asphalt in pavement ages over time and becomes more rigid. Due to environmental conditions, stiff pavement material will crack at regular intervals along the length of the roadway. Over time, these cracks widen due to additional loading and deterioration. By the early 1990's, these cracks were often up to 2 inches wide at the pavement surface.

At that time it was evident that an asphalt overlay without treating the existing thick pavements would not address future cracking in an acceptable manner. Also, future performance of any pavement rehabilitation would be reduced due to existing contaminated base materials.

Based on these issues, it was determined that full depth reclamation followed by a HMA overlay would be the most cost effective pavement rehabilitation for many roadways. The full depth reclamation process would convert the existing thick pavement materials into a base type of material. This allowed the pavement to be more flexible. Pulverization and recompaction of the asphalt materials into a less dense base material provided a minimal grade raise that is beneficial for surface drainage and could be controlled during construction. ITD modeled the Crabs process after the Roadbed Modification procedure that was in use at the time in Nevada.

530.00.02 Current Status. The situation that generated development of the Crabs process no longer exists (and never existed for local roads). Most if not all of the projects where Crabs is clearly the most viable alternate for pavement rehabilitation have been constructed. The procedure has been generally successful, although there have been a few projects where the process is considered underperforming. This is primarily due to lack of subsurface drainage and silty subgrade materials.

Currently, the Crabs process tends to be selected for rehabilitating pavements with relatively thin existing asphalt and base thicknesses where benefits to the process are minimal. ITD continues to use the Crabs process primarily for "non-materials" reasons. These reasons include familiarity with the process and a lack of specialty contractors in Idaho that use other procedures.

Other pavement rehabilitation procedures that have been used in Idaho include CIR as mentioned above and Hot In Place Recycle (HIP). While ITD is very familiar with the Crabs process, other pavement rehabilitation procedures are not unfamiliar.

Specialty contractors for procedures other than Crabs exist in nearby states. For non-Idaho contractors, there is a perception of high mobilization costs. However, Idaho contractors regularly mobilize for large distances across the state. In difficult economic times, contractors will give more attention to developing competitive bid prices.

530.00.03 Pavement Rehabilitation Construction Procedures. The following paragraphs discuss new or specialty procedures that are considered viable for use in Idaho. Each procedure has merits as well as limitations.

530.00.04 Full Depth Reclamation (FDR / CRABS) The Crabs process is a full depth reclamation process consisting of pulverizing the existing asphalt materials and a portion of the base. A portion of the material may be used to widen the shoulders. The materials are then mixed with cement, usually at the rate of 2%, and then recompacted. This is followed by a HMA overlay.

Pulverization and recompaction of the asphaltic material usually necessitates removal of approximately 10 to 20% of the material to adequately maintain the roadway grade. Most often, the material that is removed tends to be the highest quality material in the roadway.

A clean aggregate base layer is preferred for optimal performance. For projects where significant contamination of the base exists, the 2% cement additive may or may not be successful at stabilizing the materials. For projects where the existing base layer is contaminated to the point of not being effective or where no base exists, another alternative should be selected. Also, unless a minimum of about 6 inches of aggregate base or clean sand and gravel will remain intact under the Crabs layer, underlying fines may be pumped into the Crabs layer during construction. A Crabs base that is contaminated with pre-existing fines is expected to experience problems. Additionally, for roadways where the existing base consists of uncrushed materials the benefits of the Crabs process are significantly reduced.

Underperformance of pavements where the Crabs process was used has also been attributed to moisture intrusion due to a high water table or other reasons. Literature has been observed identifying stripping of asphaltic materials where Portland cement has been used as the additive. Such literature seems to imply that moisture problems may be alleviated by eliminating the cement. However, eliminating the cement from a Crabs / Full Depth Reclamation base does not address moisture problems.

The Crabs process loosens material that was previously compacted or consolidated. It has been found that most of the compaction of a Crabs base is limited to the top 4 to 6 inches of this layer when a strong aggregate base layer remains. The process reduces the stiffness strength of high quality existing asphalt pavement materials by approximately 70%. At this time, underperforming pavements in terms of design life and problems during construction are expected to increase with the Crabs process.

530.00.05 Cold In Place Recycle (CIR) This procedure consists of coldmilling up to 4 inches depth, mixing emulsified asphalt and additives, relaying the material and recompacting. Additives are included for timely stabilization of the material. Shoulders may be widened using imported RAP or crushed aggregate base material.

Performance of this procedure in Idaho was considered less than stellar in the past for various reasons. However, those issues have been successfully addressed with recent projects. A project was recently constructed on an interstate highway in Nevada.

ITD is aware of no research that identifies the reduction in stiffness strength of the pavement material when the CIR process is used. However, the depth of the process into the existing pavement is limited to approximately 4 inches. It has been suggested that the CIR layer provides a crack mitigation layer. Also, a minimum of approximately 1 to 1 ½ inches of the existing asphalt thickness remains to provide a paving platform. If this material is deteriorated, it may be beneficial for construction purposes to allow more thickness to remain. This layer provides the foundation for recompaction of the asphalt material.

Cold in place recycle is performed by a subcontractor. Selection of cold in place recycle does not preclude several prime contractors from bidding the project in the event only one CIR subcontractor is interested in the project. Paving remains the major portion of the work of a cold in place recycle project.

For rehabilitation of pavements that have previously been Crabs processed, CIR is a viable alternative. In this situation, it is likely that a portion of the Crabs base could be included in the cold recycled layer although this has not been done yet in Idaho.

Generally speaking, at this time CIR is a viable alternative for any project where the Crabs process is being considered. CIR does not address contamination of existing base materials, if such contamination exists. However, this eliminates the risk of problems associated with loosening the base material.

530.00.06 Thin Whitetopping Overlay (TWT) Thin whitetopping overlay (TWT) is a new procedure in Idaho however has been increasing in popularity over the past 15 years. One experimental project has been constructed at an intersection in Idaho with no problems being observed. Thickness of the slabs is 4” to 8” however a minimum thickness of 5” appears optimal. TWT is designed as a composite pavement and functions as a composite section. The national trend for TWT is towards use of a 6 inch by 6 ft. by 6 ft. panel.

Projects must be selected as conducive to the design. Success with TWT has been attributed to selection of appropriate projects. This includes projects where the TWT was placed on a minimum of 5” AC in good condition i.e. no moisture problems, etc. Typically, this method is most conducive to use on commuter type roadways and not heavily loaded commercial type roadways. For these roadways, TWT appears to be a cost effective alternative for pavement rehabilitation.

A design method has been developed by Colorado DOT. The method uses bridge design techniques to design the panels. Due to differences in the way Esals are calculated, the method overdesigns the panels for Idaho. However the additional PCC thickness is of negligible concern. For additional details on TWT, contact Hq Materials.

530.00.07 Hot In Place Recycle (HIR) This process recycles the top 1 to 1 ½ inch of the asphalt pavement layer. This is accomplished by heating the existing pavement, hotmilling the material, and relaying the material as new hot mixed pavement. Current practice is to use emulsified asphalt as a rejuvenating agent. HFRS-2P (high-float) emulsion seems to be preferred in states where this process is used extensively.

HIR is predominantly a pavement preservation application. Hot in place recycle, if used for pavement rehabilitation, should include a structural overlay that meets pavement design requirements.

Long project lengths (10 – 15 miles) with minimal curvature are usually preferable due to the length of the recycling train. Pavement materials should contain no cutback materials due to the tendency for this material to flame in the heating process.

Hot in place recycle is performed by a subcontractor. Selection of HIP does not preclude several prime contractors from bidding the project.

Equipment and technology of this procedure has evolved since past ITD projects. At this time, use of the Hot In Place Recycle for pavement preservation project(s) would be appropriate for evaluating current technology.

530.00.08 Crack Repair and Pavement Interlayer This procedure consists of sawcutting and removing approximately a 2 ft section of the existing pavement and base at locations where cracks are wider than ¾ inch. The pavement shall be reconstructed to pre-existing thicknesses followed by a pavement interlayer and a HMA overlay. A pavement interlayer may consist of a Stress Absorbing Layer of Straight Asphalt (SALSA) or a pavement geotextile. The pavement interlayer is intended to delay the return of cracks.

The sawcut pavement edges shall be tack coated prior to placing HMA in the reconstructed patch.

Alternative methods of crack repair may be used to reduce expenditure of funds. Equipment consisting of a cold mill or reclaimer attachment replacing the bucket on a loader arm exists and may be viable for use. Routing the cracks and filling with loose HMA immediately prior to placing the overlay appears relatively cost effective. System III Pavement Repair Geosynthetic with the physical properties shown in Section 543.03 should be considered with these alternative methods for crack repair.

SALSA consists of a heavy application of hot asphalt followed by a minimal application of cover coat material as needed to carry construction traffic. SALSA is followed immediately by the HMA overlay. Roadway traffic is not allowed on the SALSA.

SALSA seems preferred for rural applications. Some tracking of asphalt is expected with SALSA. Pavement geotextile is appropriate for locations where tracking of SALSA asphalt needs to be avoided and where paving conditions are considered difficult. When a leveling course is used, application of the SALSA and full width paving subsequent to the leveling course is considered more practical than applying the SALSA prior to the leveling course.

To avoid unsatisfactory results, all cracks that are not removed and patched (i.e. less than ¾” wide) should be blown out with compressed air prior to applying SALSA. Eliminating this effort is not cost effective.

Application rates for SALSA typically consist of 0.25 gal/sy of PG 58-34 asphalt, and 10 lbs/sy of cover coat material.

The procedures described herein are a collection of accepted methods of pavement rehabilitation design. Some have been modified to accommodate the design considerations unique to Idaho. The following is a partial list of the sources used in developing these procedures:

- AASHTO Guide for Design of Pavement Structures, 1993
- Washington State DOT, Pavement Guide, 1995
- California DOT, Manual of Test, 1978
- Cost Effective Pavement Rehabilitation Evaluation of The Interstate System – Part One, Nevada DOT, 1997
- MODULUS, Computer Program, Texas Transportation Institute
- EVERCALC and EVERPAVE, Computer Programs, Washington DOT, 1995
- WINFLEX, Computer Program, ITD / University of Idaho, 1997/2000

Alternate design methodologies may be used with permission, provided the results are compared to the result determined from the approved method. Any difference must be explained and the use of the alternate design must be justified.

530.01 Summary of Design Factors. A condition survey for rehabilitation projects is to be completed in accordance with Section 540.00 Pavement Structures Analysis. The results of the survey and design recommendations shall be included in the Phase I Materials Report for rehabilitation projects.

Consider the following major factors in developing a structural rehabilitation project.

530.01.01 Structural Quality of Existing Pavement. The existing pavement structure is composed of layers of material that may have degraded or otherwise become deficient in quality since the time of original construction. The presence of moisture in the pavement structure can contribute to cracking and stripping in the surface course and can promote pumping in fine-grained subgrade soils, leading to contamination of base course aggregate. The pavement condition survey provides the evaluation of the structural quality of the existing section. A condition survey should reflect the actual condition of the pavement structure on a section-by-section basis.

With the actual layer thicknesses, analyze the deflection data to develop back-calculated moduli for the various pavement layers and the subgrade for each of the homogeneous segment developed using the CONVERSN program.

Calculate the existing structural capacity and additional ballast requirements, if needed, using both the back-calculated moduli from deflection tests and the laboratory R-Value test data (component analysis). Deflection-based methods will most often yield slightly lower additional ballast requirements since the deflection data represents the stabilized, in-place condition of the pavement layers.

530.01.02 Traffic. Evaluate traffic data according to Section 510.02, carefully considering past and estimated future traffic loading. The design period for major rehabilitation strategies is normally 20 years for flexible pavements. For rigid pavements rehabilitation design periods vary from 18 to 36 years. If a lesser design period is justified, use the design traffic loading appropriate for the reduced design period. In no case shall a rehabilitation strategy be designed for less than 8 years on federally funded projects. Regardless of the intended design life of the project, the design alternatives for flexible pavements should be evaluated for both 20 year and the shorter determined project life. Minimum layer thicknesses may result in a design life much greater than the minimum.

530.01.03 Climatic Factors. The climatic factors described in Section 510.05 are used to adjust the roadway structure thickness, in a component analysis, to account for the detrimental effects of climate on the ability of the structural cross section to support traffic loading. Use the appropriate climatic factors when the rehabilitation design is based on R-value.

530.01.04 Deflection Under Wheel Load. It is possible for a pavement structure to be adequately designed on the basis of R-value or expansion pressure, yet exhibit higher than normal deflections due to the presence of moisture and resilience of the subgrade soils. Conversely, many pavements that appear to be inadequate structurally, based on component analysis, may exhibit lower than expected deflections due to good drainage or subgrade strength gain.

530.01.05 Economic Factors. Design the alternate rehabilitation strategies to accommodate the estimated traffic loading for the design period appropriate to the specific strategy and use the life cycle cost to determine the most economical alternate. Life cycle cost analysis is described in Section 541.00.

530.02 Flexible Inlay / Overlay of Flexible Pavement.

530.02.01 Design by Deflection Analysis. The design procedures outlined below are based, in part, on methodologies used by Washington DOT, Texas DOT, California DOT and the Strategic Highway Research Program (SHRP). Much of the methodology and data manipulation programs have been developed within the Idaho Transportation Dept. A summary of the theory underlying deflection based analysis and design is presented in Section 530.08.

530.02.01.01 Deflection Testing. Deflection testing (FWD) is performed by the Pavement Testing Unit in Headquarters Materials. The District Materials Engineer will submit requests for deflection testing to the Pavement Design Engineer prior to the beginning of the field testing season in April. The standard deflection testing program consists of the following:

- FWD tests will be made in at least one direction on two lane roadways and on the travel lane in both directions on four lane roadways. The testing interval should be not longer than 0.1 mile (160 meters). Intermediate tests should be made in localized areas of significantly different distress.

- Test locations will be in the outer wheel path on flexible pavements unless otherwise directed. On rigid pavement test locations will be in the center of the slab except for load transfer across joints. Where rutting is too deep to achieve uniform contact with the loading plate, the test point will be relocated so that the plate makes adequate contact.

- Tests will be made with at least one force level of 9,000 to 12,000 lb. (40–55 kN). Once every ten tests, at least two force levels will be used; one under and one over 9000 lb. (40 kN).

- Indicate the degree of distress at the point of test in the comments column of the data file. Use the SHRP Distress Identification Guide. In addition indicate whether test point is in cut or fill.

- The FWD crew chief will deliver a diskette with the field deflection data. (FWD files) to the District Materials Engineer prior to leaving the district.

- The file naming convention is as follows. Route #, Direction, Lane (multilane sections), and Milepost plus appropriate file extension, Example: S41A0032 – State Highway 41, Ascending direction, Milepost 32. I84D1013 – Interstate 84, Descending direction, Passing lane, Milepost 13.

A zero or one in the position after the direction designates travel lane, or passing lane respectively. This may cause problems for route numbers with 3 digits and more than 100 mile (160 km) length, a condition not currently existing in Idaho. With DOS based Dynatest software Version 25 the naming convention is limited to 8 characters.

530.02.01.02 Deflection Data Reduction. The computer program MODULUS, developed by the Texas DOT and Texas Transportation Institute, is the primary deflection analysis tool used by ITD to back-calculate pavement layer stiffnesses (moduli). See Section 530.08.01 for a detailed description of analysis using MODULUS.

As a check on the results of the MODULUS program, EVERCALC, version 4.0 (developed by Washington DOT(WSDOT) and University of Washington) is recommended at each milepost. Two force levels are required at each test point for the program to normalize the moduli to a 9000 lb. (40 kN) wheel load. The program also corrects the calculated moduli to 77ºF (25ºC). A more detailed description of the program is presented in Section 530.08.02 and in the WSDOT Pavement Guide.

Note: *In back-calculation programs, it is extremely important that layer thicknesses be as accurate as possible. Variations of as little as 10% in asphalt pavement thickness can make significant differences in the calculated moduli. See Section 540.00 for recommendations for the Pavement Condition Survey.*

530.02.01.03 Calculation of Required Inlay / Overlay. Two programs are available for use in calculating required inlay or overlay thickness based on deflection analysis. EVERPAVE (MSDOS Version 1.1 and WINDOWS 95 Version 5.0), developed by the Washington DOT and University of Washington, and WINFLEX developed specifically for WINDOWS 95 & NT by the University of Idaho, for the Idaho Transportation Dept. Specific information on both of these programs is contained in the respective user's manuals; the Washington DOT Pavement Guide and the report generated for ITD Research Project 121. Program descriptions, summaries of recommended input parameters and operating suggestions for EVERPAVE are presented in Manual Section 530.08.03, and for WINFLEX in 530.08.04.

530.02.02.01 Inlay / Overlay Requirements by Component Analysis. The design procedure described below is based on the methods developed by the California Dept. of Transportation, which have been modified to conform to the Idaho design process and to Idaho conditions.

530.02.02.02 Substitution Ratios for Existing Pavement Materials. Assign substitution ratios to common paving materials according to Section 510.06, except as noted below:

- For base course aggregates that do not meet present specification and quality requirements, i.e., R-value, sand equivalent, and gradation, reduce the substitution ratio to that of granular subbase (R-value 60 or greater) or to that of granular borrow as appropriate. For Rock Cap, which has degraded or has been infiltrated by subgrade soils, reduce the substitution ratio to that of aggregate base.

- For plant mix or road mix pavements that exhibit alligator or block cracking, raveling or stripping, reduce the substitution ratio proportionately to the extent of the distress (not to exceed a total reduction of 30%). If the 30% reduction will result in a substitution ratio of less than 1.0, use 1.0.

- Cement treated bases, which exhibit severe cracking and deterioration should be replaced. However, If the cement treated base is intact and is to be retained in the short term, The substitution ratio should be the same as that for aggregate base. Use substitution ratios applicable to plant mix surfacing for plant mix base.

530.02.02.03 Computing the Inlay / Overlay Thickness. Compute the overlay thickness using the procedures of Sections 510.03 through 510.06. Determine the thickness in gravel equivalency required based on the R-value of each layer in the pavement structure and the R-value and expansion pressure of the subgrade. To determine inlay/overlay requirements, replace the existing plant mix with new plant mix to the depth of the desired inlay and re-compute the required overlay.

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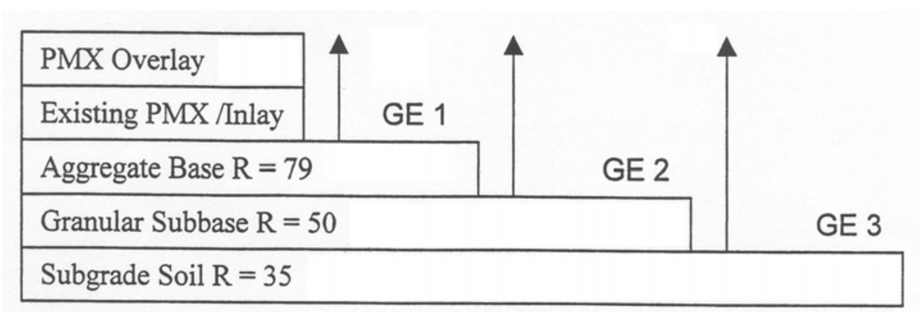
530.02.02.04 Design Example. Assume an existing two-lane highway composed of 0.30 ft. (90 mm) plant mix surfacing, 0.50 ft. (150 mm) crushed aggregate base, and 1.0 ft. (300 mm) granular subbase. The condition survey indicates that the existing plantmix surface is rough, but shows little evidence of rutting, raveling or stripping. Alligator cracking covers approximately 5% of the total pavement surface and block cracking covers approximately 15% of the total pavement surface. The aggregate base meets all current specifications and quality requirements, with an R-value of 79. The subbase is reasonably clean and free of excess minus 0.074 mm (#200) material, with an R-value of 53. The sandy silt subgrade R-Value is 35. No drainage deficiencies are apparent.

With a thin overlay, the cracks may reflect through relatively quickly, therefore, a combination of inlay and overlay may provide the best solution to the structural requirements, smoothness and crack propagation.

Current design data are as follows:

	1997		2017
Accumulated ESALS (Design Lane)	30,000		1,750.000
Subgrade R-value		35	
Subgrade expansion pressure In psi (kPa)		0.60 (4.1)	
Unit weight, base and surface In pcf (kg/m^3)		130 (2080)	
Climatic Region		2	

Begin by making a sketch of the existing pavement cross-section and the inlay / overlay to be designed.



Calculate the design ESALS.

ESALS = 1,750,000 – 30,000 = 1,720,000

Calculate the Traffic Index.

$TI = 9.0\ (1{,}720{,}000 / 10^6)^{0.119}$
$TI = 9.6$

Calculate the ballast requirement for all layers of the pavement structure existing above the base course, including the proposed overlay.

GE 1 = 0.0032 (9.6)(100 – 79)(1.05) = 0.68 ft.

GE 1 = 0.975 (9.6)(100 – 79)(1.05) = 206 mm

Calculate the overlay thickness, applying the appropriate substitution ratios, subtracting the value of the existing plant mix surface (reduced substitution ratio).

$$T = \frac{0.68\,\text{ft} - 0.30\,\text{ft}(1.8 \text{ x } 0.8)}{1.8}$$

T = 0.138 ft., use 0.15 ft.
GE 1 (actual) = (.15 ft. × 1.8) + (.30 ft. × 1.44) = 0.70 ft

$$T = \frac{206\,\text{mm} - 90\,\text{mm}(1.8 \text{ x } 0.8)}{1.8}$$

T = 42 mm, use 45 mm
GE 1(actual) = (45 mm × 1.8) + (90 mm × 1.44) = 211 mm

Calculate the ballast requirement for all layers of the pavement structure existing above the subbase, including the proposed overlay.

GE = 0.0032 (9.6)(100 – 53)(1.05) = 1.52 ft.

GE = 0.975 (9.6)(100 – 53)(1.05) = 462 mm

Calculate the overlay thickness applying the appropriate substitution ratios, subtracting the value of the existing plant mix surface (reduced substitution ratio) and aggregate base.

$$T = \frac{152.\text{ft} - ((0.3\,\text{ft x } 1.44) + (0.5\,\text{ft x } 1.0))}{1.8}$$

T = 0.33 ft., use 0.35 ft.
GE 2 (actual) = 0.35 ft. × 1.8) + (0.3 × 1.44) + (0.5 ft/ × 1.0) = 1.56 ft.

$$T = \frac{462\text{mm} - ((90\text{mm x } 1.44) + (150\text{mm x } 1.0))}{1.8}$$

T = 101 mm, use 105 mm

GE 2 (actual) = (105 mm × 1.8) + (90 mm × 1.44) + (150 mm × 1.0) = 469 mm

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Calculate the ballast requirement for all layers of the pavement structure existing above the subgrade soil, including the proposed overlay.

GE = 0.975 (9.6)(100 -35)(1.05) = 639 mm

GE = 0.0032 (9.6)(100–35)(1.05) = 2.10 ft.

Calculate the overlay thickness applying the appropriate substitution ratios, subtracting the value of the existing plant mix, base and subbase (reduced substitution ratios as appropriate).

$$T = \frac{2.10\text{ ft} - ((0.3\text{ ft x }1.44) + (0.5\text{ ft x }1.0) + (1.0\text{ ft.x }0.75))}{1.8}$$

T = 0.23 ft., use 0.25 ft.

GE 3 (actual) = (0.25 ft × 1.8) + (0.30 ft × 1.44)
+ (0.50 ft × 1.00) + (1.0 ft × 0.75) = 2.13 ft.

$$T = \frac{639\text{ mm} - ((90\text{ mm x }1.44) + (150\text{ mm x }1.0) + (300\text{ mm x }0.75))}{1.8}$$

T = 74.6 mm, use 75 mm

GE 3 (actual) = (75 mm × 1.8) + (90 mm × 1.44) +
(150 mm × 1/0) + (300 × 0.75) = 640 mm

Review the overlay thicknesses from each set of calculations above, to determine which controls the design. The greatest overlay thickness is based on the R-value of the subbase. Therefore the subbase is the controlling layer and an overlay thickness of 0.35 ft. (105 mm) is selected.

Because of the thickness of the overlay, it would be advisable to provide an alternate consisting of reconstructing the base and surfacing to meet the ballast requirements of the subbase. Another alternate to be considered for reducing the overlay thickness is an inlay / overlay. Calculations for this alternate design are as follows:

Calculate the overlay thickness required in conjunction with a 0.15 ft (45 mm) inlay. Apply the appropriate substitution ratios, subtracting the value of the remaining existing plant mix and aggregate base (reduced substitution ratio for the remaining existing plant mix). The required ballast thickness over the subbase is 1.52 ft. (462 mm), as calculated above. *Note: Actual inlay and overlay lift thickness is governed by the nominal aggregate particle size; see Section 510.00.*

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$$T = \frac{1.52\text{ ft} - ((0.15\text{ ft x }1.8) + (0.15\text{ ft x }1.44) + (0.50\text{ ft x }1.0))}{1.8}$$

T = 0.30 ft, use 0.30 ft
GE 2 (actual) = (0.30 ft × 1.8) + (0.15 ft × 1.8) +
(0.15 ft × 1.44) + (0.50 ft × 1.0) = 1.53 ft

$$T = \frac{462\text{ mm} - ((45\text{ mm x }1.8) + (45\text{ mm x }1.44) + (150\text{ mm x }1.0))}{1.8}$$

T = 92 mm, use 90 mm*
GE 2 (actual) = (90 mm × 1.8) + (45 mm × 1.8) + (45 mm × 1.44) + (150 mm × 1.0) = 459 mm

**Convention dictates that the required overlay thickness be rounded up to the next highest multiple of 15 mm. Because of rounding, the English and metric systems do not exactly agree. An overlay of 90 mm is used here to agree with the results of the computation in the English system.*

By using a 0.15 ft. (45 mm) inlay, the overlay is cut from 0.35 ft (105 mm) to 0.30 ft. (90 mm). However, the total new asphalt plant mix placed increased to 0.45 ft. (135 mm). The overall asphalt thickness is reduced by about 0.05 ft. (15 mm), and the total of uncracked plant mix has increased to 0.45 ft. (135 mm). Crack propagation will be slowed with the increased thickness and the additional lift will increase smoothness. Even so this does not appear to be an economical alternative, but serves to illustrate the procedure.

Now, check the actual pavement thickness including the overlay against the thickness required by expansion pressure.

T (actual) = 0.30 ft + 0.30 ft + 0.5 ft. + 1.0 ft. = 2.10 ft.

$$B = \frac{0.60\text{ psi x }144}{1.30\text{ pcf}} = 0.66\text{ ft.} < 2.10\text{ ft., OK}$$

T (actual) = 90 mm + 90 mm + 150 mm + 300 mm = 630 mm

$$B = \frac{4.1\text{ kPa x }102{,}000}{2082\text{ kg/m}^3} = 200\text{ mm} < 630\text{ mm, OK}$$

The final overlay thickness is 0.30 ft. (90 mm).

530.03 Rigid Overlay of Flexible Pavement. Refer to the design procedures in Section 520.00. Assume the case of a new PCC pavement placed over plant mix pavement or asphalt treated base.

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530.04 Flexible Overlay of Rigid Pavement. A flexible overlay is a feasible rehabilitation alternative for PCC pavements, either intact, cracked or broken and seated or rubblized, except when the condition of the existing pavement dictates substantial removal and replacement. Severe deterioration of joints and cracks, severe aggregate reactivity, and inadequate right of way to allow widening slopes and raising signs and guardrails are conditions which render a flexible overlay infeasible.

The recommended design methods presented here are intended for jointed plain concrete pavement only. Currently only one continuously reinforced concrete pavement section exists in Idaho.

Prior to design of flexible overlays of rigid pavement, perform a pavement condition survey as outlined in Section 540.00.

The following types of distress should be repaired prior to placement of a flexible overlay over rigid pavement:

- Working cracks
- Spalled Joints
- Punchouts
- Deteriorated previous repairs
- Pumping / faulting
- Settlement or heaves

530.04.01 Overlay Design by Pavement Deflection Analysis. The back calculation programs used in deflection analysis of flexible pavement are not appropriate for determining the modulus of base and subbase under rigid pavement, although may be suitable for estimating surface concrete modulus, subgrade k-value and load transfer. Finite element analysis is typically used to analyze deflection tests on concrete. The overlay design programs currently in use are designed for flexible pavements.

Illinois has developed deflection-based techniques such as ILLIBACK for deflection analysis on rigid pavements. Further analysis of rigid pavement analysis and overlay design programs will be made by the Materials Section. The following sections provide methods for calculating dynamic subgrade modulus and concrete modulus from deflection tests as presented in the 1993 AASHTO Guide for Design of Pavement Structures.

For overlays over cracked and seated concrete pavement, the methods of presented in 530.02.01 are appropriate. Both the literature and ITD deflection testing indicate that the modulus of the cracked and seated concrete is on the order of 6900 kPa (1,000,000 +/- psi). To minimize crack reflection the modulus of the cracked and seated slabs should not be greater than 6900 kPa (1,000,000 psi).

Base course moduli may be obtained through back calculation of deflection data on cracked and seated concrete pavement using the methods of 530.02.01. Overlay designs using the methods of 530.02 appear appropriate for cracked and seated concrete pavement.

Deflection based analysis may be possible on broken and seated concrete, but analysis of rubblized sections will need component analysis. The rubblized concrete should be assigned a substitution ratio equivalent to aggregate base.

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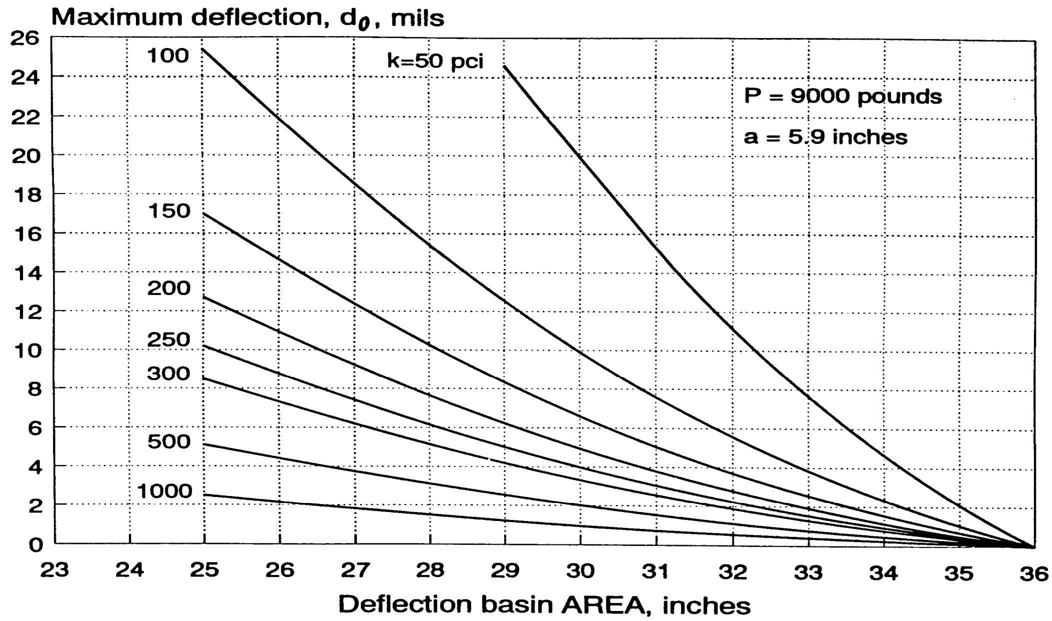
530.04.01.01 Calculation of Effective k-value. The effective k-value or Modulus of Subgrade Reaction can be determined from back calculation or alternately from the Area of each deflection basin. The Area may be calculated from the deflections at 12, 24 and 36 inches (300, 600 and 900 mm) from the center of the FWD loading plate. The deflections are based on a load magnitude of 9000 lb. (40 kN). For loads within 2000 lb (9 kN) of the standard load, the deflections can be scaled linearly. The Area is calculated as follows:

$$AREA = 6 (1 + 2 (d_{12} / d_0) + 2 (d_{24} /d_0) +(d_{36} / d_0))$$

Where d_0, d_{12}, d_{24} and d_{36} are the deflections at the center of the load plate, and at 12, 24, and 36 inches respectively. Area will typically range from 29 to 32 inches for sound concrete.

Using the Area calculated above enter Figure 530.04.01.1 to determine the effective dynamic k-value. Static k-value is dynamic k-value / 2 for cohesive soils. For granular soils the ratio is 1.0.

Figure 530.04.01.1 − Effective Dynamic K -Value Determination from D_0 and Deflection Basin Area
(1993 AASHTO Guide for Design of Pavement Structures Figure 5.10)



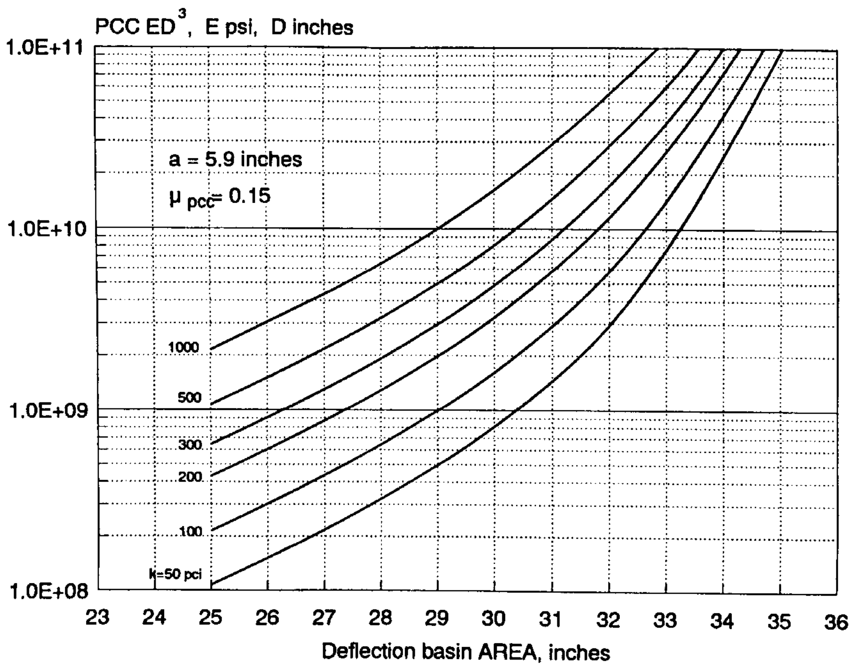
Note: *Data in the AASHTO Guide for the Design of Pavement Structures is not yet presented in metric units.*

530.04.01.02 Calculation of Concrete Pavement Modulus. The elastic modulus of the concrete pavement can be determined from back calculation, or alternately from the Area of each deflection basin. The Area may be calculated from the deflections at 12, 24 and 36 inches (300, 600 and 900 mm) from the center of the FWD loading plate The deflections are based on a load magnitude of 9000 lb. (40 kN) For loads within 2000 lb (9 kN) of the standard load, the deflections can be scaled linearly. The Area is calculated using the relationship presented above in Section 530.04.01.01.

Using the Area calculated above enter Figure 530.04.01.2 to determine the effective concrete modulus. The modulus of the concrete will normally be in the range of 3 million to 8 million psi (20,700 to 55, 200 MPa). If modulus values obtained are out of this range, an error may exist in the assumed slab thickness, the deflection basin may have been measured over a crack or the concrete may be significantly deteriorated.

If an overlay thickness is being designed for a uniform section, use the average of dynamic modulus of subgrade reaction and modulus of concrete for the section.

Figure 530.04.01.2 − PCC Elastic Modulus Determination from K-Value, Area, and Slab Thickness
(1993 AASHTO Guide for the Design of Pavement Structures, Fig. 5.11)



530.04.02 Overlay Design Based on Structural Deficiency. This method is taken directly from the 1993 AASHTO Guide. The overlay thickness is calculated as follows:

$$D_{ol} = A\,(D_f - D_{eff})$$

Where:

D_{ol} = Depth or thickness of overlay (inches)

A = Factor to convert PCC thickness deficiency to Asphalt Concrete overlay thickness

D_f = PCC slab thickness to carry future traffic (inches) (Determine in accordance with Section 520.00)

D_{eff} = Effective thickness of existing slab (inches)

The factor A, which is a function of PCC slab thickness deficiency is given by the following relationship and can be determined graphically from Figure 530.04.2.

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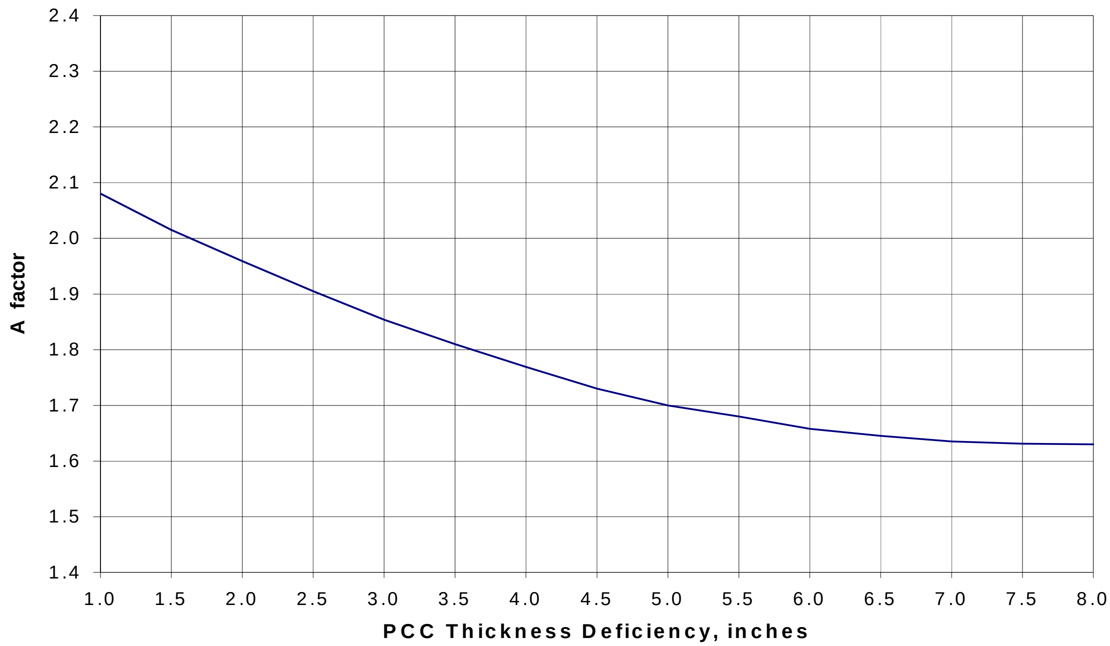
Figure 530.04.2 – A Factor for Conversion of PCC Thickness Deficiency To Ac Overlay Thickness
(1993 AASHTO Guide For Design Of Pavement Structures Fig 5.9)



$A = 2.2233 + 0.0099(D_f – D_{eff})^2 – 0.1534 (D_f - D_{eff})$

Calculate the slab thickness, D_f, required to carry future traffic as in Section 520.00.

Determine the effective thickness, D_{eff}, of the existing concrete pavement from the results of the condition survey. On concrete pavement, the condition survey should contain information on the following:

- Number of deteriorated transverse joints per mile
- Number of deteriorated transverse cracks per mile
- Number of full-depth asphalt concrete patches, exceptionally wide joints (>25mm or 1in.), and expansion joints per mile, (except at bridges)
- Presence and general severity of PCC durability problems, such as reactive aggregate cracking
- Evidence of pumping of fines or water

From the condition survey, the effective thickness of the existing slab (D_{eff}) is computed from the following equation:

$D_{eff} = F_{jc} \times F_{dur} \times F_{fat} \times D$

Where:

D = Existing slab thickness in inches.

F_{jc} = Joints and cracks Adjustment Factor (Figure 530.04.02.1)

F_{dur} = Durability Adjustment Factor (530.04.02.02)

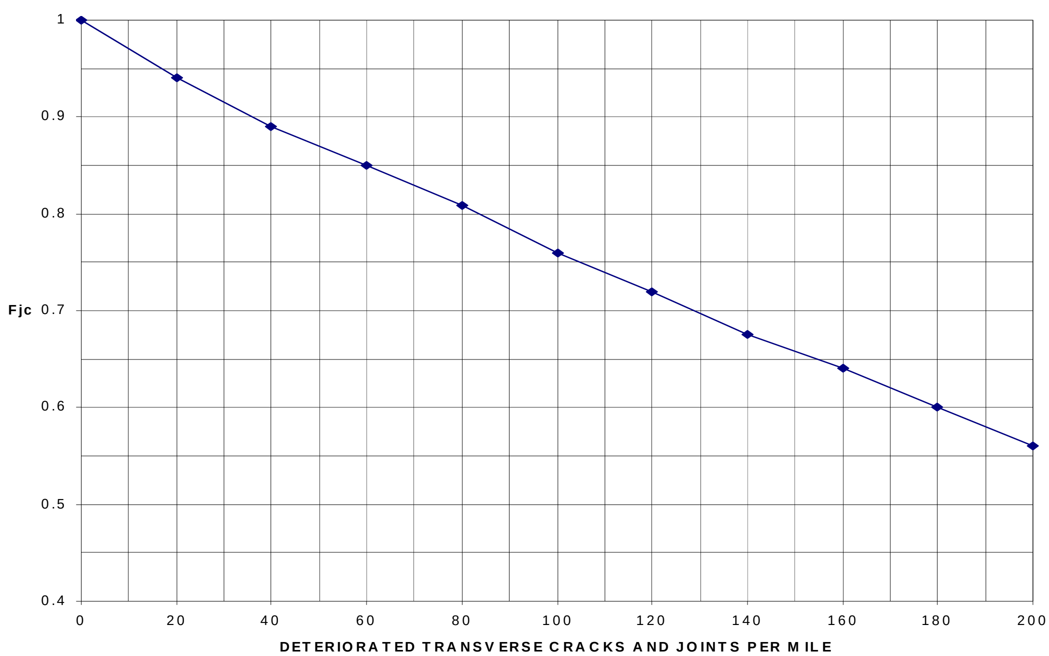
F_{fat} = Fatigue Damage Adjustment Factor (530.04.02.03)

Each of these factors is explained in the following subsections.

530.04.02.01 Joints and Cracks Adjustment Factor. This factor adjusts for the extra loss in Present Serviceability Index (PSI) caused by deteriorated reflection cracks in the overlay that will result from any unrepaired, deteriorated joints, cracks and other discontinuities existing prior to overlay. Therefore, all deteriorated joints and cracks (not related to durability distress) should be repaired full-depth with doweled or tied concrete.

If it is not possible to repair all deteriorated joints, cracks and major discontinuities, the total number of unrepaired, deteriorated cracks, joints, wide joints (>1 in. or 25 mm), and full-depth, full-lane asphalt patches per mile is used to determine the F_{jc} from Figure 530.04.02.1.

Figure 530.04.02.1 − F_{jc} Adjustment Factor (1993 AASHTO Guide for the Design of Pavement Structures, Fig. 5.12)



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530.04.02.02 Durability Adjustment Factor. This factor adjusts for an extra loss in PSI of the overlay when the existing slab has durability problems. Using the results of the condition survey determine F_{dur} as follows.

F_{dur}	Condition
1.00	No sign of durability problems
0.96 – 0.99	Aggregate reactivity cracking exists, no spalling
0.88 – 0.95	Substantial durability cracking and some spalling exists
0.80 – 0.87	Extensive durability cracking and severe spalling exists

530.04.02.03 Fatigue Damage Adjustment Factor. This factor adjusts for past fatigue damage that may exist in the slab. It is determined by observing the extent of transverse cracking (Plain Jointed PCC) or punchouts (CRCP) that may be caused primarily by repeated loading. Use condition survey data and the following guidelines to estimate F_{fat} in the design lane.

F_{fat}	Condition
0.97 – 1.00	Few transverse cracks / punchouts
JPCP:	< 5 percent slabs are cracked
CRCP:	< 4 punchouts per mile (3 per kilometer)
0.94 – 0.96	A significant number of transverse cracks / punchouts
JPCP:	5 – 15 percent slabs are cracked
CRCP:	4 – 12 punchouts per mile (3 – 8 per kilometer)
0.90 – 0.93	A large number of transverse cracks / punchouts
JPCP:	> 15 percent slabs are cracked
CRCP:	> 12 punchouts per mile (>8 per kilometer)

530.05 Cement Recycled Asphalt Base Stabilization (CRABS). The CRABS process, or Full Depth Reclamation is a recycling process in which all of the existing asphalt pavement and in most cases at least a portion of the existing aggregate base is pulverized (rototilled) full depth to a maximum particle size of 2 inches (50 mm) mixed with a small amount of cement and reshaped and compacted into base for a new surface course. Other additives, emulsified asphalt or hydrated lime, may be substituted for the cement under specific conditions.

Not all pavement rehabilitation projects are suitable candidates for the CRABS process. The best candidates for CRABS rehabilitation are structurally adequate with relatively thick asphalt surfaces and sufficient aggregate base to allow pulverizing and mixing at least a thickness of 8 inches (200 mm) without penetrating through the base. The CRABS thickness may vary on a project specific basis. However, the process must extend completely through any asphalt layers. Ideally the aggregate base should make up 50% or less of the total pulverized and remixed material.

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Typical surface distress on projects with a high CRABS potential are transverse thermal cracking, rutting and raveling. Pavements exhibiting extensive fatigue distress (alligator cracking) may not be good candidates for CRABS rehabilitation, since a thick new surface course may be required to achieve structural adequacy. When the existing pavement is pulverized, the pavement section is significantly weakened and susceptible to traffic damage until a new surface is placed.

By pulverizing the entire thickness of the existing asphalt surface, the cracks are completely removed. A small amount of cement (on the order of 2% of the weight of the pulverized material) is added to bind the fines and provide some added stiffness to the pulverized material. Compressive strengths of the mixture after cement has hydrated and cured should be less than 400 psi (2750 kPa) to prevent the brittleness and transverse cracking potential associated with traditional cement treated base.

The CRABS treated material cannot be compacted back to its original density. Therefore, there is usually a 10 to 20% increase in volume, requiring trimming and removal of the excess where existing finished grades are to be maintained. Often, blading off the excess prior to complete pulverization and mixing results in removal of the best material. It is preferred that all of the CRABS material remain on the grade, which requires a small grade raise.

Design of CRABS sections has been based on the deflection measurements made either prior to construction or when possible after the CRABS has been placed. The subgrade modulus derived from the deflection testing and base course modulus, if it is to remain intact, are used in conjunction with a typical modulus for the CRABS to design the thickness of the new asphalt concrete surface course using the methods of Section 530.02.01.03 and Section 530.08.

Based on limited data, a design modulus value of 100,000 to 150,000 psi has been developed. If the thickness of aggregate base included in the CRABS is significant, the modulus may be lower. As more data is collected, modifications to the recommended design modulus will be made. In analysis, the CRABS is considered to act as a slightly cemented aggregate and is not treated as temperature sensitive. While this is not strictly accurate, currently there is no data to support a temperature correction.

The minimum surface course thickness which should be placed over a CRABS is 0.2 ft (60 mm). On Interstate highways the recommended minimum surface course thickness is 0.3 ft (90 mm). On other NHS routes with heavy truck traffic the recommended minimum surface course thickness is 0.25 ft (75 mm).

Table 530.05.1-Estimated Cement Requirement for Crabs

$$W = paT$$

where:
W = weight of cement in lb/SY (kg/m^2)
a = maximum density of pulverized material, lb/CY (kg/m^3) (assumed if value is not known)
p = percent of cement by volume
T = depth of soil to be mixed, feet (meters)

If d= 6 inches or 0.5 ft and P= 2% or 0.02, then		If d= 150 mm and P= 2% or 0.02, then	
W= (p)(a)(T)=0.02 x 135 lb/CF x 0.5 ft. x 9 SF/SY		W= (p)(a)(T)=0.02 x 2150 kg/m^3 x 0.15 m	
	$\boxed{W = 12.2 \text{ lb/SY}}$		$\boxed{W = 6.5 \text{ kg/m}^2}$
If d= 8 inches or 0.67 ft.	$\boxed{W = 16.3 \text{ lb/SY}}$	If d= 200 mm	$\boxed{W = 8.6 \text{ kg/m}^2}$

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If d= 10 inches or 0.83 ft.	W = 20.2 lb/SY	If d= 250 mm	W = 10.8 kg/m^2
If d= 12 inches or 1.0 ft.	W = 24.3 lb/SY	If d= 300 mm	W = 12.9 kg/m^2
From Soil Stabilization With Portland Cement, Bomag 1987.			

530.06 Hot In-Place Recycling (HIR). Hot in-place recycling of asphalt pavement is performed by heating the existing pavement, hot milling the surface and relaying the milled material as new hot mixed pavement. Typically the depth that can be achieved is approximately 2 inches (50 mm). Some equipment has been modified with an additional heater to extend the milling depth to 3 inches (75 mm). Milling is accomplished by two or more milling heads, each removing about 1 inch (25 mm). The maximum particle size required is 2 inches (50 mm). The milled material is windrowed and picked up, remixed and laid down through a conventional paver. The hot in-place recycling train contains all units necessary to heat, mill, mix and place the material in one pass. Additional aggregate can be added in the process to correct gradation and /or asphalt content. A rejuvenating agent can also be added to soften age-hardened asphalt.

With proper speed, the resulting milled material can be heated to temperatures nearly as high as plant mixing. The resulting surface is considered to be equal to new plant mix, although, to reduce the potential for raveling, a seal coat or thin plant mix seal is recommended. Because of the shallow depth of treatment, hot in-place recycling will only delay the reflection of pre-existing cracks.

Asphalt seal coats, roadmix pavements and moisture in the pavement surface will all reduce the heating ability of the recycling equipment, requiring reduced production. Asphalt surface treatments (seal coats) will, on the average, add about 0.5% asphalt to the milled pavement for each treatment. Milling and disposing of asphalt surface treatments should be considered on any hot in-place recycling project.

Pre-coated aggregate added to the process can improve existing gradations. Most recycling systems have the capacity to add up to about 65 lb per square yard (35 kg per square meter) of additional material. A few systems are capable of adding enough material to add significant thickness to the pavement. An additional thickness of .05 ft. (15 mm) of would require 66 lb/sq yd (33 kg/sq m) of additional material.

It is extremely important to get representative samples from any potential hot in-place recycling project. Coring appears to be the best method to collect existing surfacing for analysis. Non-uniformity of the pavement to be recycled can seriously reduce the effectiveness of the recycled product.

The average anticipated life of a hot in-place recycled surface has not been determined. However, a life of 5 to 8 years is probable if the pavement is otherwise structurally sound. Hot in-place recycling should be considered on structurally adequate pavements to re-level the surface, eliminate ruts and to temporarily remove cracks. It can also be used effectively as a leveling course under a proposed overlay. The number of times a pavement can be hot, in-place, recycled has not been established. But, at least 3 times is likely.

Design of a hot in-place recycled section, used as a leveling course, will be essentially the same as for an inlay/overlay using the methods of Sections 530.02.01.03 and 530.08. The output of the program would be the thickness of overlay required over the recycled section.

530.07 Cold In-place Recycling (CIR). Cold in-place recycling of flexible pavement is a process in which the existing pavement is cold-milled either partial or full depth, mixed with a hydrated lime slurry and emulsified asphalt and/or a rejuvenating agent and relayed. Because the material is cold-milled there is no temperature requirement and as a result the process can extend deeper into the existing pavement. The particle size requirements are the same as for hot in-place recycling; (2 inches or 50 mm). Additional aggregate may be added to the milled material with some equipment systems.

Because the milled material is mixed with an emulsified binder or rejuvenator the final mix contains as significant amount of water. This will dissipate over time, but final compaction must be delayed until the moisture content drops to 1% or less. Also, because the material is milled and laid cold, the compacted density may be significantly less than for hot mix. Air void contents typically run in the 10-12% range. As a result of the added asphalt binder, the recycled material is temperature sensitive, and will act as an asphalt base in analysis.

Currently the range of moduli for cold recycled plant mix has not been clearly established. A modulus at 77°F (25°C) of not more than 200 ksi may be appropriate for the combined layer of cold in place recycle and underlying bituminous material until new information becomes available. Until more information becomes available, use the range of moduli shown in Table 530.08.3 for the purposes of deflection based design.

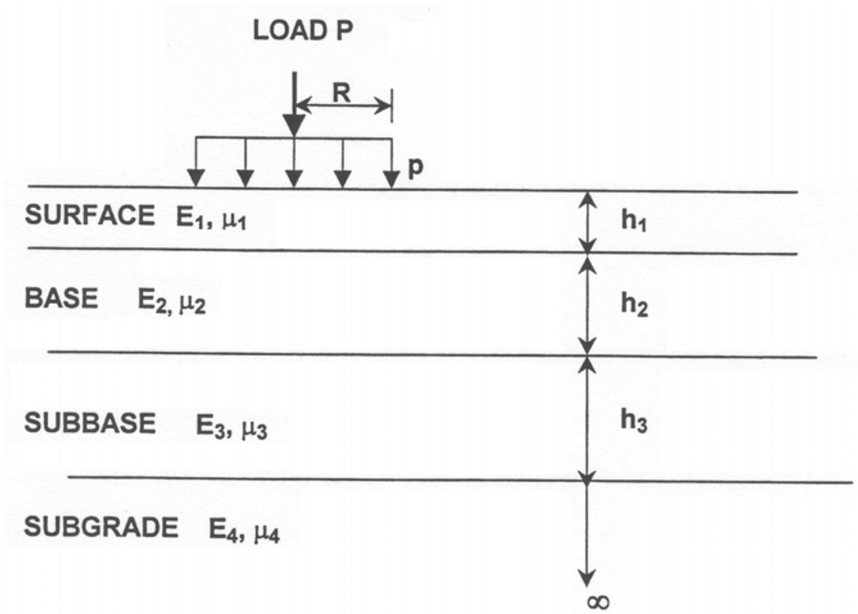
Because of the probable high void content, a substantial surface course should be placed over cold in-place recycled asphalt pavement in all but the low volume roads. The potential for raveling and rutting are significant. A minimum surface course thickness of 0.2 ft (60 mm) is recommended over cold in-place recycled pavement. Interstate and heavily loaded Primary routes will require more. A deflection analysis should be performed on completed cold in-place recycled pavements to assess the surface course needs.

Cold in-place recycling is appropriate as a leveling course for an overlay, provided the planned overlay meets the minimum thickness requirements.

530.08 Deflection Based Analysis and Design. Deflection based, or mechanistic-empirical design is based on measurement of pavement responses to imposed load, such as, stresses, strains, and deflections of the pavement layers, through the use of mathematical models. These responses are related empirically to the pavement performance or life. The mathematical models relate the deflection under load to the stresses and strains produced in each pavement. From the stresses and strains, the mechanical properties (stiffness or elastic moduli) can be calculated. The stiffness values are then used to determine the structural adequacy of the pavement structure, and/or structural improvements needed.

The primary tool in the mechanistic analysis of pavement structures is the Falling Weight Deflectometer (FWD), which measures the deflection of the pavement surface under a dynamic load, at several locations beneath and adjacent to the loading plate. The maximum deflection and the shape of the deflection basin are related to the mechanical properties of the pavement layers through a ‘back-calculation process. The back calculation process uses a mathematical model to calculate the stiffness (modulus) of each pavement layer. Generally the model used is a layered, elastic analysis. Figure 530.08.1 illustrates the layered elastic model. The model assumes that individual pavement layers are homogeneous, isotropic and infinite in lateral extent. The subgrade thickness is assumed infinite unless there is a hard layer assumed at depth. A four-layer model is shown; however the base and subbase often are sufficiently similar to be combined for a three-layer analysis.

Figure 530.08.1 − Layered Elastic Pavement System



In the above figure, **P** represents the force applied to the surface of the pavement. Lower case **p** represents the contact pressure by the loaded area. **R** is the radius of the loaded surface. The thickness of each layer is represented by **h**. Each layer is represented by the modulus (**E**) and Poisson's ratio (μ). Typical values of Modulus and Poisson's ratio are presented in Table 530.08.3.

Layer thickness must be known within about 10% at each test point to achieve reasonable results. Figure 530.08.2 shows the effect of varying stiffness on deflection measurements.

Figure 530.08.2 − Comparative Deflection Basins

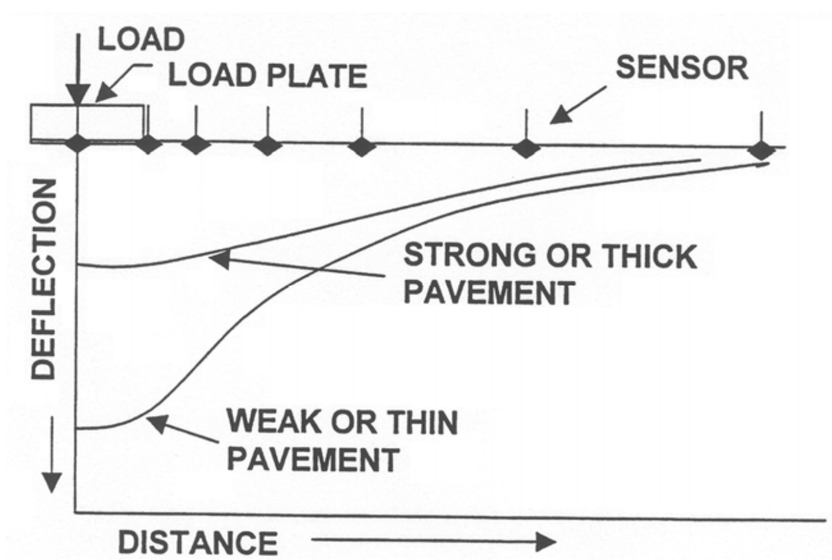


Table 530.08.3 – Typical Values of Modulus and Poisson's Ratio for Pavement Layers

530 MATERIAL	MODULUS (KSI)	POISSON'S RATIO
Asphalt Concrete (Surface & Base)	400 @ 77°F	0.35
Crushed Aggregate Base [(1)]	25 - 70	0.40
Granular Subbase [(1)]	15 - 50	0.40
CRABS	100 - 150	0.35 – 0.40
Cold In-Place Recycled Asphalt Concrete	150 - 200	0.35 – 0.40
Asphalt Treated Permeable Base	200 - 300	0.35
Rock Cap	25 - 60	0.40
Subgrade – Fine Grained	< 20	0.45
Subgrade – Coarse Grained	5 - 35	0.40 – 0.45

[(1)] Where possible should be combined into one layer for analysis.

A number of computer programs are available to perform the back-calculation analysis. Two programs are in use by the Department: MODULUS, developed by the Texas Transportation Institute; and EVERCALC, developed by the University of Washington and Washington DOT. There are several versions of each program and recommendations for use will refer to the most current version distributed unless otherwise stated. **Note:** *Many of the programs and models available for analysis and design do not currently have metric capability. Therefore all of the figures are presented in English units only.*

Evaluation of existing pavements and design of pavement rehabilitation alternatives using deflection analysis is essentially the reverse of the back-calculation process. The thicknesses, moduli and Poisson's ratio for each of the pavement layers are input. The forward calculation process, again elastic layer analysis, calculates the stresses and strains and deflections under a design wheel load. The lateral strains at the bottom of an asphalt layer (fatigue) and the vertical strain at the subgrade level (rutting) are compared to predetermined failure criteria. Rutting is difficult to evaluate. Rutting can occur in any layer. A large portion of the rutting occurring on Idaho highways is confined to the upper lifts of the asphalt surface, and is a mix problem. Rutting in the subgrade is usually accompanied by premature fatigue failure in the wheel paths. Failure criteria have been developed by several agencies and researchers, primarily from laboratory testing. Currently considerable emphasis is being placed on data from accelerated loading facilities. These data will significantly influence the failure criteria in the future.

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Fatigue Models

Failure criteria developed by the Asphalt Institute and Shell Oil is the most commonly used. Fatigue model equations usually take the form of:

$$N_f = f_1 \times \varepsilon_t^{-f_2} \times E_{ac}^{-f_3}$$

Where:

N_f = number of load applications to failure in lab tests,

ε_t = tensile strain at the bottom of the asphalt layer, and

E_{ac} = dynamic modulus of the asphalt layer (psi), and

f_1, f_2,f_3 are constants derived from the analysis of laboratory tests.

Several of the sources for fatigue models neglect the asphalt modulus term. Asphalt Institute, Shell Research and the Army Corps of Engineers include it. Several fatigue model equations are plotted as shown on Figure 530.08.4. The Asphalt Institute equation is shown below.

Asphalt Institute fatigue Model:

$$N_f = \left[(4.32 \times 10^{-3})\,(\varepsilon_t)^{-3.29}\,(E_{ac})^{-0.854}\right]$$

Where:

N_f = number of load applications to failure in lab tests.

ε_t = tensile strain at the bottom of the AC layer, and

E_{ac} = dynamic modulus of the AC layer (psi).

The above equation is multiplied by the following factor to reflect differences in asphalt and air void contents:

$C = 10^M$ Where C is a function of air voids (V_v) and asphalt volume (V_b)

$$M = 4.84\left[(V_b / V_v + V_b) - 0.69\right]$$

Subgrade Strain (Rutting):

$$\varepsilon_v = 1.05 \times 10^{-2}(1/N)^{0.223}$$

Where:

ε_v = compressive strain at the subgrade surface, and

N = number of load applications which should not result in more than 0.5 in. (13 mm) of rutting at the pavement surface.

Rewriting the equation to solve for N:

$$N = \left[1.05 \times 10\text{-}2 / \varepsilon_v\right]^{4.4843}$$

Shell Method:

The Shell method includes the ability to estimate the effect of horizontal loads on layer interfaces with variable friction, and looks at the permanent deformation of the Asphalt surface.

Fatigue:

$$N_f = \left[4.91 \times 10^{-13} (0.856V_b + 1.08)^{5.00} (1/\varepsilon_t)^{5.00} (1/E_{ac})^{1.80}\right]$$

Where:

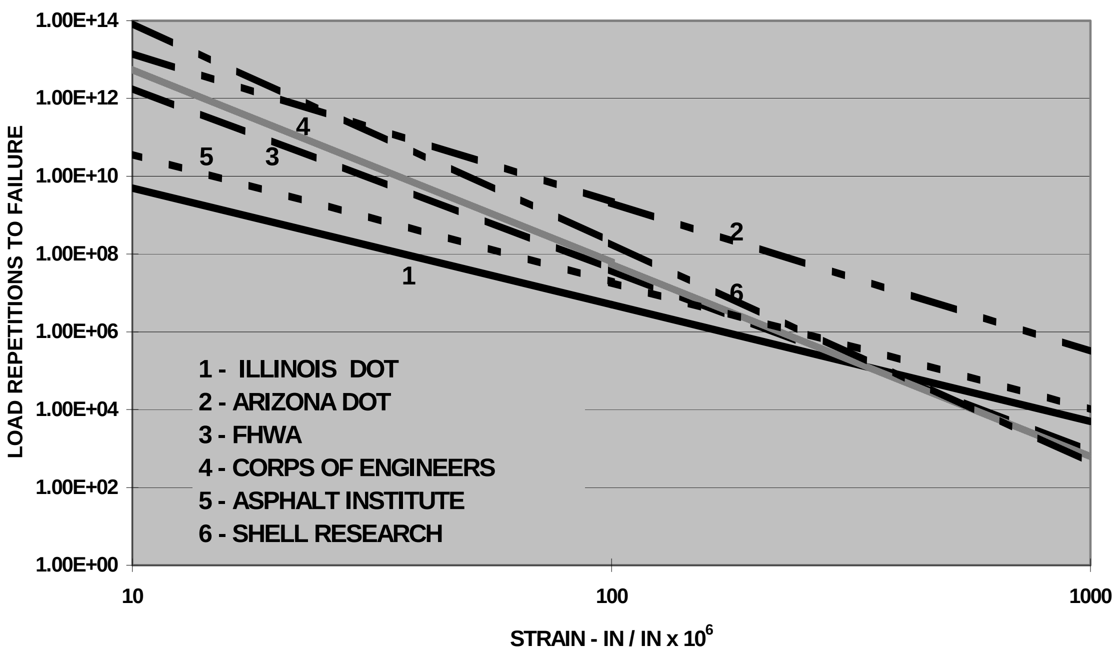
N_f = number of load applications to cause failure in lab tests,

V_b = volume of asphalt in mix,

ε_t = horizontal tensile strain at the bottom of the AC layer, and

E_{ac} = dynamic modulus of the asphalt layer (ksi)

Figure 530.08.4 − Fatigue Equations



Subgrade Rutting:

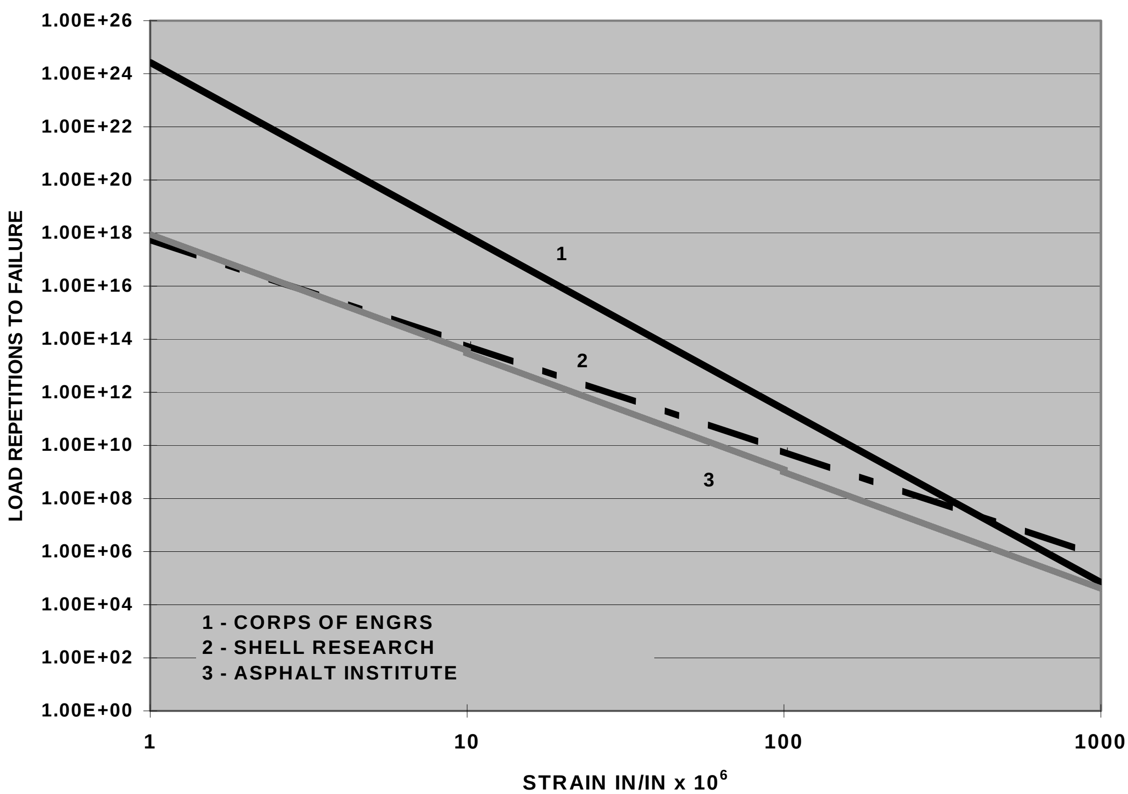
$$N = \left[2.8 \times 10^{-2} / \varepsilon_v\right]^4$$

Where:

N = number of strain repetitions and

ε_v = vertical strain at the top of the subgrade

Figure 530.08.5 − Subgrade Rutting Models



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Shift Factor:

The fatigue equations have been predominantly developed from either the AASHTO road test or from laboratory analysis. The Asphalt Institute and Illinois methods are essentially laboratory failure mechanisms. There is a difference between the definition of failure in the laboratory and that in actual service. This difference requires that a correction factor be applied to the laboratory fatigue equations to recognize the longer fatigue life observed in the field.

$N_{field} = N_{lab}$ (F)

Where:

N_{lab} = number of load repetitions to failure from lab data, and

N_{field} = number of load repetitions to failure for field conditions

Finn and the Asphalt Institute recommended shift factors for new pavement of 10 for 10% fatigue cracking in the wheel paths, and 18.4 for 20% cracking.

The University of Illinois developed the following Shift Factors for the Bonnaure fatigue equation (AAPT, 1980) which are also applicable to the Asphalt Institute equation.

12.32 - 10% or less fatigue cracking in the wheel paths

16.20 - 20% or less fatigue cracking in the wheel paths

The Washington State DOT Pavement Manual recommends values between 4 and 10. With 10 being applicable to new pavement and thinner intact pavements. Values toward the lower end of the range are recommended for thick (>7 in. or 180 mm) existing pavements because maximum tensile strains occur in the upper portion of the layer. Where cores of thinner existing pavements show tensile cracking, the Shift Factor should be toward the lower end of the range

The Shell Research Model is reported to be correlated to field performance. Therefore, Shift Factors of 1.0 (one) should be used with this model.

Current ITD practice recommends Shift Factors between about 4 and 12 for the Asphalt Institute or Illinois models. Higher values should be used for new pavement and for existing pavement with little evidence of fatigue cracking. Shift factors toward the lower end of the range should be used for thicker existing pavement (>7 in. or 180 mm) and those thinner pavements exhibiting fatigue cracking. Where the existing pavement exhibits extensive alligator cracking on the surface, fatigue analysis may not be appropriate. Where fatigue cracking is present, the modulus of the asphalt surfacing at 77ºF (25ºC) will be considerably lower than that for new pavement.

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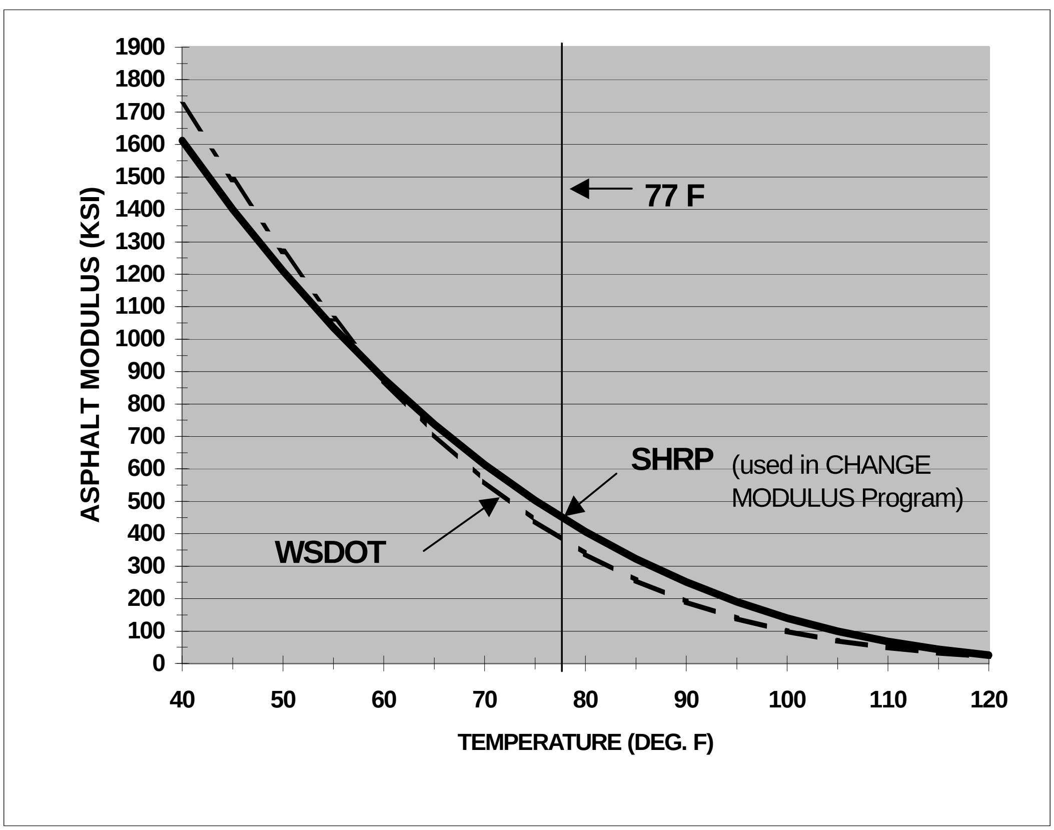
Temperature Correction:

During deflection testing, the mid-depth temperature of the asphalt pavement is measured directly or can be calculated from air temperature data, using BELLS-3 or Southgate methods. Due to the distance and elevation differences between many project sites and established weather stations, direct measurements of mid-depth temperatures using SHRP procedures should be made on all projects. The mid-depth temperature is recorded hourly during testing, and at the beginning and ending of a test section. Since the modulus of the asphalt surfacing is dependent on the temperature, the modulus derived from back calculation must be corrected to 77ºF (25ºC) before input to design programs. Several correlations between temperature and modulus of asphalt concrete are available. Variations between these correlations occur due to variations in the viscosity of the asphalt used. Currently good correlations for polymer modified asphalt are not common. The effect is to flatten the curve. As these correlations become available, they will be included in the design process. Data from the Washington State DOT and from the Strategic Highway Research Program (SHRP) has been used to develop the correlation used by ITD. This is presented graphically in Figure 530.08.6. A computer program has been developed to make the correction and automatically insert the modulus into the output from the back-calculation process. This will be described in the following sections.

Figure 530.08.6 – Asphalt Modulus Versus Temperature



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530.08.01 Deflection Analysis Using MODULUS. Modulus is an elastic analysis back- calculation program developed by the Texas Transportation Institute and the Texas DOT. The following discussion pertains to MODULUS Version 5.1, which is an MSDOS program designed to run in WINDOWS 95 or NT.

The field data are contained in the .FWD file. Using the FWDPREP program, create the .OUT file, which is the input to MODULUS. Typically the third drop is used. Examine the .FWD file to be sure that the third drop is representative of a stable condition. Also check for comments regarding the distress observed and whether the section is in cut or fill. Input the .OUT file into the CONVERSN program to evaluate the cumulative differences in deflection and to isolate uniform segments of the project (see the 1993 AASHTO Guide, Appendix J). The .OUT file should be separated into individual files for each of these segments. Use these data to determine where cores and exploratory borings should be located.

Run the MODULUS program using the .OUT files as input. The number of layers, loading plate radius, sensor spacing, thickness data and modulus ranges for each layer are input manually. The plate radius is 5.91 in. (150 mm) and the sensor spacing currently used is the SHRP spacing: 0, 8, 12, 18, 24, 36, 60 inches (0, 203, 305, 457, 610, 914, 1524 mm). One draw back is the inability to input layer thicknesses at each test point. Average values for the analysis section are used.

Examine the results and adjust the input modulus ranges as necessary to eliminate as many of those locations where modulus values are at the limits of the range. It is often advisable to alter the input modulus ranges and rerun the program. If, in the rerun results, the moduli for some locations are significantly different from the initial runs, those locations are considered unstable and should be eliminated before doing further analysis. Any location should be eliminated if the deflections do not decrease as distance from the load plate increases. An * on a data line indicates that the moduli are out of the input range. Change the input range to eliminate the *.

It is desirable to limit the error per sensor to approximately 2%. This is not always possible and in most cases, errors in the 3-5% range may not adversely affect the subsequent analysis. One or more of the following error reduction methods may be used to minimize the error per sensor.

- On a three-layer system, isolate about 12 in. (300mm) of the subgrade (or section thicker than the overlying base and subbase) and include as a separate layer. Do not include this as a separate layer above subgrade in design.

- On a four-layer system or when the base or subbase is thinner than the asphalt surface, the upper about 12 in. (300mm) of subgrade may be included within the subbase. During design this option may result in an erroneous estimate of subgrade rutting potential.

- After all other error reduction measures are applied locations with a significantly high error should be eliminated from the analysis.

- Change the stiff or hard layer modulus. If the error appears to be predominantly in the 7th sensor, the stiff or hard layer modulus may not be appropriate for the project. The stiff layer, modular ratio can be altered by pressing F9 from inside the program. The preset default value for stiff or hard layer modulus is about 1,000 ksi (6,895 MPa). A 50 ksi (345 MPa) value is more appropriate for many stiff layer conditions. A groundwater table in fact will return a stiff layer estimate of about 50 ksi. (345 MPa). Another alternative on thin pavement sections is to eliminate the 7th sensor.

Figure 530.08.01.1 shows the flow path for analysis using MODULUS. An example field data or .fwd file is shown in Figure 530.08.01.2, an example .out file is shown in Figure 530.08.01.3. The .DAT or output file, which is the input data for EVERPAVE 1.1, is shown in Figure 530.08.01.4 and the Summary File which is the file included in the published report is shown in Figure 530.08.01.5.

Figure 530.08.01.1– Flow Chart Analysis of FWD Data Using Modulus

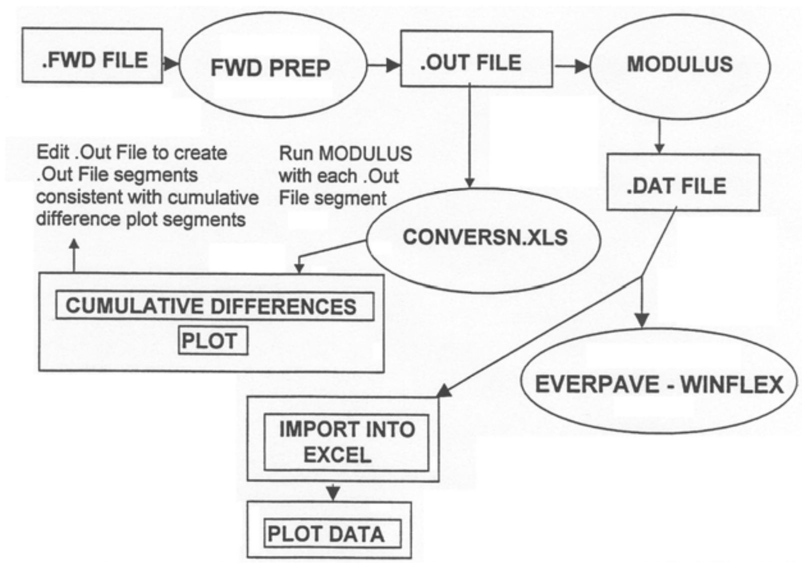

Figure 530.08.01.2 − Example Field Data (.FWD) File

```
R80    117   910514C55A001236F20
700031008002-09377808.8103111  8
150 0   203 305 457 610 914 1524 5.9   0     8     12    18    24    36    60
C:\FWD\TESTDATA\              .FWD
3SH055002005
S  12.740D51 13      16 12 114   55  61  54  Heights ...........................
S  12.740D51 13      16 12 118   55  61  54  Heights ...........................
800 20802730373012.43    12.74
8   15   3.5 5    2   15   10  8
Ld 144   1     88.14
D1 1251  1     1.023
D2 1252  1     1.010
D3 1253  1     1.005
D4 1254  1     1.007
D5 1255  1     1.001
D6 1256  1     1.007
D7 1257  1     1.012
D0 1258  1     1.021
D* ***** 1     1
D* ***** 1     1
JOANNE PAYNE
11010300.......................
6   .5  3   .5   ..............
*000+0.0 000+0.0 st
FMMDDYYD
FMMDDYYD
*000+0.0 000+0.0 st
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10422   -10422      0   1Peak...32  0   .....

12345........................................................................
CC3333122223333444411111111111111111111111111111111111111111114444444444444444
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......*...*...*...*..........................................................
"FLEX TESTING, STANDARD/SHRP
*000+0.0 000+0.0 st
S  12.430A50 13      12 10 I3093355  53  49  Heights ..........................
 741 460 374 318 242 184 113  59 11767 18.10 14.73 12.51  9.53  7.23  4.44  2.33
 738 459 373 316 242 183 114  60 11727 18.06 14.67 12.45  9.51  7.22  4.48  2.34
 734 456 369 314 240 182 114  59 11659 17.94 14.54 12.35  9.45  7.17  4.49  2.31
 '
S  12.450A50 13      12 10 I3093455  53  49  Heights ..........................
 738 450 369 311 235 182 112  57 11719 17.70 14.53 12.23  9.26  7.16  4.41  2.22
 734 448 369 309 234 181 111  56 11663 17.62 14.54 12.16  9.23  7.11  4.38  2.19
 732 446 368 308 233 180 111  56 11628 17.54 14.47 12.11  9.19  7.10  4.38  2.19
 '
S  12.470A50 13      13 10 I3093655  54  49  Heights ..........................
 734 524 422 353 265 200 124  62 11659 20.61 16.61 13.91 10.45  7.89  4.88  2.44
 731 521 420 351 263 200 123  66 11612 20.49 16.52 13.83 10.37  7.88  4.85  2.59
 728 520 418 351 265 200 124  65 11572 20.46 16.47 13.80 10.44  7.87  4.89  2.55
 '
EOF
```

(**Note:** See FWD Operator’s Manual for a description of the fields in the FWD file.)

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Figure 530.08.01.3 − Example .OUT File (Input for Modulus)

D F	RTE	MP	LOAD	R1	R2	R3	R4	R5	R6	R7
3 53	SH055	12.430 0	11659	17.94	14.54	12.35	9.45	7.17	4.49	2.31
3 53	SH055	12.450 0	11628	17.54	14.47	12.11	9.19	7.10	4.38	2.19
3 54	SH055	12.470 0	11572	20.46	16.47	13.80	10.44	7.87	4.89	2.55
3 56	SH055	12.489 0	11592	19.96	16.69	14.29	11.17	8.78	5.60	2.85
3 56	SH055	12.509 0	11532	20.91	17.57	15.33	12.22	9.74	6.32	3.11
3 56	SH055	12.528 0	11564	20.50	16.92	14.43	11.20	8.79	5.65	2.91
3 57	SH055	12.548 0	11624	21.70	18.29	15.75	12.30	9.70	6.21	3.21
3 57	SH055	12.568 0	11461	19.80	16.89	14.63	11.58	9.12	6.02	3.30
3 58	SH055	12.587 0	11338	18.75	15.37	13.09	10.14	7.90	5.18	2.76
3 59	SH055	12.607 0	11338	19.90	16.60	14.09	10.94	8.51	5.56	3.22
3 59	SH055	12.626 0	11560	21.33	18.13	15.68	12.49	9.89	6.40	3.41
3 59	SH055	12.646 0	11604	21.15	17.22	14.77	11.72	9.17	6.05	3.19
3 59	SH055	12.665 0	11306	22.36	19.18	16.63	13.21	10.47	6.81	3.46
3 59	SH055	12.685 0	11207	22.37	18.67	16.02	12.38	9.66	6.04	2.67
3 62	SH055	12.705 0	11262	20.57	17.39	15.06	12.04	9.67	6.40	3.35
3 60	SH055	12.740 1	11318	17.09	14.33	12.44	9.92	8.00	5.53	3.07
3 59	SH055	12.740 1	11457	18.06	15.46	13.19	10.33	8.13	5.31	2.80
3 60	SH055	12.740 1	11195	17.34	13.99	11.72	8.87	6.77	4.22	2.28
3 60	SH055	12.740 1	11199	17.47	14.15	11.86	8.87	6.80	4.37	2.59
3 61	SH055	12.740 1	11266	17.84	14.32	11.92	9.04	6.92	4.56	2.31

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Figure 530.08.01.4 − Example Modulus Output File (.DAT)

D	F	RTE	MP	Load	R1	R2	R3	R4	R5	R6	R7	E1	E2	E3	E4	
3	53	SH055	12.4300	11658	17.94	14.54	12.35	9.45	7.17	4.49	2.31	936225.	20114.	40322.	10692.	&
3	53	SH055	12.4500	11627	17.54	14.47	12.11	9.19	7.10	4.38	2.19	915365.	23808.	29222.	11470.	&
3	53	SH055	12.4700	11571	20.46	16.47	13.80	10.44	7.87	4.89	2.55	578295.	35079.	10473.	12060.	&
3	53	SH055	12.4890	11591	19.96	16.69	14.29	11.17	8.78	5.60	2.85	926216.	22176.	23518.	8783.	&
3	53	SH055	12.5090	11531	20.91	17.57	15.33	12.22	9.74	6.32	3.11	863256.	32937.	10139.	8670.	&
3	53	SH055	12.5280	11563	20.50	16.92	14.43	11.20	8.79	5.65	2.91	795929.	23498.	24737.	8469.	&
3	57	SH055	12.5480	11623	21.70	18.29	15.75	12.30	9.70	6.21	3.21	911202.	19463.	21443.	7995.	&
3	57	SH055	12.5680	11460	19.80	16.89	14.63	11.58	9.12	6.02	3.30	922074.	32558.	11201.	9081.	&
3	57	SH055	12.5870	11337	18.75	15.37	13.09	10.14	7.90	5.18	2.76	803714.	26142.	28147.	8970.	&
3	57	SH055	12.6070	11337	19.90	16.60	14.09	10.94	8.51	5.56	3.22	816919.	23197.	25166.	8495.	&
3	57	SH055	12.6260	11559	21.33	18.13	15.68	12.49	9.89	6.40	3.41	891412.	29698.	10204.	8664.	&
3	57	SH055	12.6460	11603	21.15	17.22	14.77	11.72	9.17	6.05	3.19	728553.	26484.	23578.	7795.	&
3	57	SH055	12.6650	11305	22.36	19.18	16.63	13.21	10.47	6.81	3.46	882811.	26450.	9425.	8014.	&
3	57	SH055	12.6850	11206	22.37	18.67	16.02	12.38	9.66	6.04	2.67	825593.	17173.	19846.	8126.	&
3	60	SH055	12.7050	11261	20.57	17.39	15.06	12.04	9.67	6.40	3.35	803028.	35082.	10888.	8106.	&
3	60	SH055	12.7401	11317	17.09	14.33	12.44	9.92	8.00	5.53	3.07	1599996.	16671.	10561.	13959.	*
3	60	SH055	12.7401	11456	18.06	15.46	13.19	10.33	8.13	5.31	2.80	1007807.	31093.	15076.	10080.	
3	60	SH055	12.7401	11194	17.34	13.99	11.72	8.87	6.77	4.22	2.28	825421.	22250.	38896.	10820.	&
3	60	SH055	12.7401	11198	17.47	14.15	11.86	8.87	6.80	4.37	2.59	834519.	19210.	59999.	9830.	*
3	60	SH055	12.7401	11265	17.84	14.32	11.92	9.04	6.92	4.56	2.31	685836.	27547.	35754.	9936.	&

Figure 530.08.01.5 – Example Modulus Summary Report

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.

Dstrict 3
County: 61
Highway/Road: SH055

Thickness(in)		MODULI RANGE(psi)) Minimum	Maximum	Poisson's Ratio Values
Pavement:	4.20	600,000	2,000,000	H1: ŏ = 0.35
Base:	8.40	10,000	70,000	H2: ŏ = 0.40
Subbase:	12.00	10,000	70,000	H3: ŏ = 0.40
Subgrade	112.20	13,100		H4: ŏ = 0.45

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens.	Depth to Bedrock
12.430	11,658	17.94	14.54	12.35	9.45	7.17	4.49	2.31	1179.	28.7	29.4	11.6	0.49	126.53
12.450	11,627	17.54	14.47	12.11	9.19	7.10	4.38	2.19	1249.	26.5	31.1	11.8	0.31	118.20
12.470	11,571	20.46	16.47	13.80	10.44	7.87	4.89	2.55	1037.	17.4	39.1	10.2	0.33	126.44
12.489	11,591	19.96	16.69	14.29	11.17	8.78	5.60	2.85	2000.	13.6	10.0	13.4	3.95	128.23 *
12.509	11,531	20.91	17.57	15.33	12.22	9.74	6.32	3.11	1261.	32.9	18.6	8.2	0.18	119.44
12.528	11,563	20.50	16.92	14.43	11.20	8.79	5.65	2.91	1055.	28.0	26.5	8.9	0.12	132.11
12.548	11,623	21.70	18.29	15.75	12.30	9.70	6.21	3.21	1275.	21.6	23.4	8.3	0.27	135.79
12.568	11,460	19.80	16.89	14.63	11.58	9.12	6.02	3.30	2000.	11.1	19.5	10.6	2.41	168.15 *
12.587	11,337	18.75	15.37	13.09	10.14	7.90	5.18	2.76	1077.	30.5	30.3	9.4	0.37	144.18
12.607	11,337	19.90	16.60	14.09	10.94	8.51	5.56	3.22	1098.	27.2	27.0	8.9	0.53	223.23
12.626	11,559	21.33	18.13	15.68	12.49	9.89	6.40	3.41	1340.	27.1	19.0	8.2	0.19	153.84
12.646	11,603	21.15	17.22	14.77	11.72	9.17	6.05	3.19	1028.	26.1	32.6	7.9	0.52	143.64
12.665	11,305	22.36	19.18	16.63	13.21	10.47	6.81	3.46	2000.	11.1	10.0	9.6	3.05	130.19 *
12.685	11,206	22.37	18.67	16.02	12.38	9.66	6.04	2.67	1105.	20.4	21.1	8.3	0.16	96.22
12.705	11,261	20.57	17.39	15.06	12.04	9.67	6.40	3.35	1398.	18.2	38.8	7.1	0.14	143.48
12.740	11,317	17.09	14.33	12.44	9.92	8.00	5.53	3.07	1332.	37.9	37.1	8.3	0.35	172.72
12.740	11,456	18.06	15.46	13.19	10.33	8.13	5.31	2.80	1453.	29.9	24.8	9.8	0.78	140.24
12.740	11,194	17.34	13.99	11.72	8.87	6.77	4.22	2.28	1076.	27.7	33.1	11.6	0.18	128.22
12.740	11,198	17.47	14.15	11.86	8.87	6.80	4.37	2.59	1033.	28.1	35.0	11.2	0.79	166.56
12.740	11,265	17.84	14.32	11.92	9.04	6.92	4.56	2.31	901.	32.1	35.8	10.6	0.68	117.86
Mean:		19.65	16.33	13.96	10.87	8.51	5.50	2.88	1295.	24.8	27.1	9.7	0.79	136.80
Std. Dev:		1.76	1.65	1.55	1.36	1.16	0.79	0.41	335.	7.4	8.7	1.6	1.06	22.76
Var Coeff(%):		8.94	10.09	11.07	12.51	13.68	14.45	14.20	26.	29.8	32.2	16.8	134.22	16.64

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Some additional tips in running MODULUS:

- Errors in thickness of 10% in the asphalt surface can produce significant errors in the asphalt modulus. Errors produced by mismeasurements of 10% in the base and subbase may occur, but will be less pronounced. The subgrade modulus is the most accurate.

- The program may not give reasonable modulus values for layer thicknesses less than about 2.5 in. (65 mm). For thin layers, an assigned modulus may be necessary or the thin layers of like materials combined.

- The thickness of each layer should be equal to or greater than that of the layer above. If individual base and subbase layers are thinner than the asphalt surface layer, these layers should be combined in the analysis. Combining base and subbase layers is suggested to reduce the computation time unless the quality of the layers is significantly different.

- The maximum number of layers is four, in addition to the stiff layer.

- To plot the deflection or modulus data, transfer the data to a spread sheet, don't use the plotting routine in the program.

530.08.02 Deflection Analysis Using EVERCALC. The current version of EVERCALC is 5.0 and is designed to run in Windows 95 or NT. EVERCALC is based on multi-layer elastic pavement analysis program CHEVNL or Chevron N-layer. From an initial rough estimate of layer moduli (seed moduli), the program iteratively searches for the "final" modulus for each layer. This is defined when the root mean square (RMS) error of the discrepancy between calculated and measured surface deflections falls within the specified range or when the change in modulus is within the specified allowable tolerance. The program will also terminate when the specified number of iterations is reached.

When two or more load levels are available at a test location, EVERCALC computes the coefficients of stress sensitivity. The layer moduli are normalized to a 9000 lb (40 kN) load, and the asphalt bound layer modulus can be normalized to 77°F (25°C).

Seed moduli may be user defined or for pavements of 3 layers or less, the seed moduli may be estimated from a set of internal regression equations. The closer the seed moduli are to the final values, the quicker and more accurately the program will determine these final values. With a little experience, user estimated seed moduli are preferred.

The RMS error and modulus tolerance should be set at 1%. Normally 10 iterations is adequate.

A flow chart for analysis using EVERCALC is shown in Figure 530.08.02.1.

EVERCALC requires that the user choose the method of field temperature measurement. In almost all cases the direct measurement should be chosen rather than the Southgate method which requires 5 days site specific temperature data.

The maximum number of layers that can be analyzed is five including the stiff layer. Use of a stiff layer is optional, but has been found to be necessary in improving the deflection discrepancy. The presence of a stiff layer has a tendency to decrease the modulus of the subgrade and increase the base modulus. This option is part of the development of the General Data file (.GEN).

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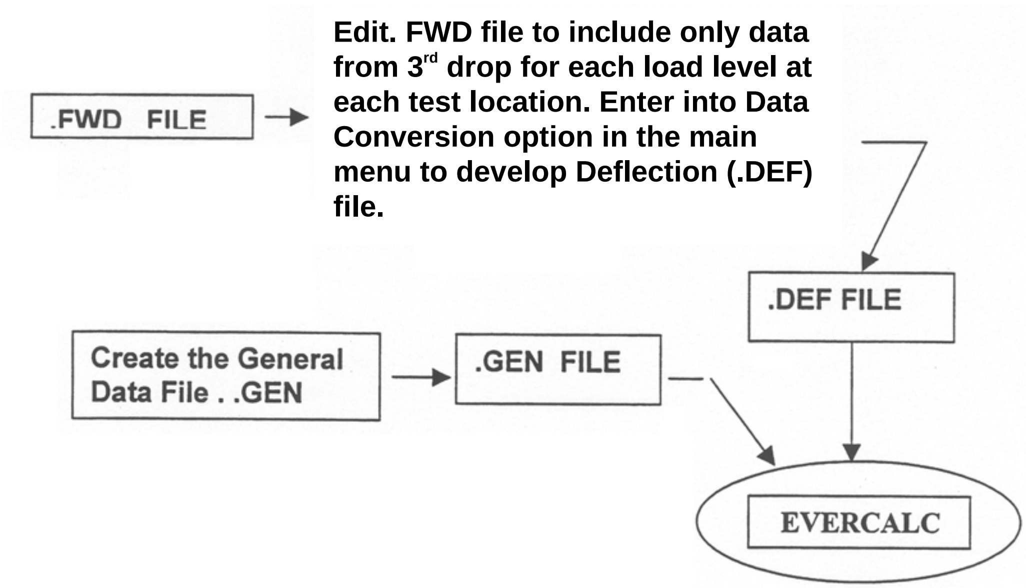
Figure 530.08.02.1 – Flow Chart – Fwd Analysis with EVERCALC 5.0



General Data File:

Inputs required are number of layers, units (metric or English), load plate radius (use 5.91 in., 150 mm), Number of sensors (typically 7) and the spacing. The sensor spacing is given in the previous section. An example General Data File is shown in Figure 530.08.02.2. The locations at which stresses and strains are to be measured are also input into the General File. A location for stress and strain measurement must be input for each layer. An example of this input is shown in Figure 530.08.02.3.

The field data conversion option in EVERCALC 5.0 has been updated to be compatible with Version 25 currently in use by ITD Therefore the deflection file can be developed using the data conversion option. EVERCALC requires the use of two load levels, one above 40 kN (9000 lb) and one below, in order to normalize moduli to 9000 lb (40 kN). ITD standard practice has been to run multiple load levels at one-mile intervals, these data are appropriate for input into EVERCALC. To develop the deflection file (.DEF), edit the .FWD file to include only the data from the 3rd drop for each load level, at each station to be entered. Layer thicknesses are input in the .DEF file, so can be varied at each station as can the pavement temperature. EVERCALC will report the moduli at 77ºF (25ºC). An example of the deflection (.DEF) file is shown on Figure 530.08.02.4.

To create a new file inside the program, the file must be given a name then open the file. Using Save As and the new file name will over-ride previous file names. Names such as A.GEN or A.DEF can be used to bring up a blank form.

Output from EVERCALC is in two forms. Detail Output shows all stresses and strains as well as moduli and K1 and K2 values for nonlinear analysis. The Detail Output requires one sheet for each station analyzed. The Output Summary, which shows only the calculated moduli and the moduli normalized to 9000 lb. (40 kN). The program will run even if both load levels are above or below 9000 lb. (40 kN), however, there will be no normalized values. Figures 530.08.02.5 and 530.08.02.6 illustrate these two output forms.

Figure 530.08.02.2 – Example EVERCALC General Data File

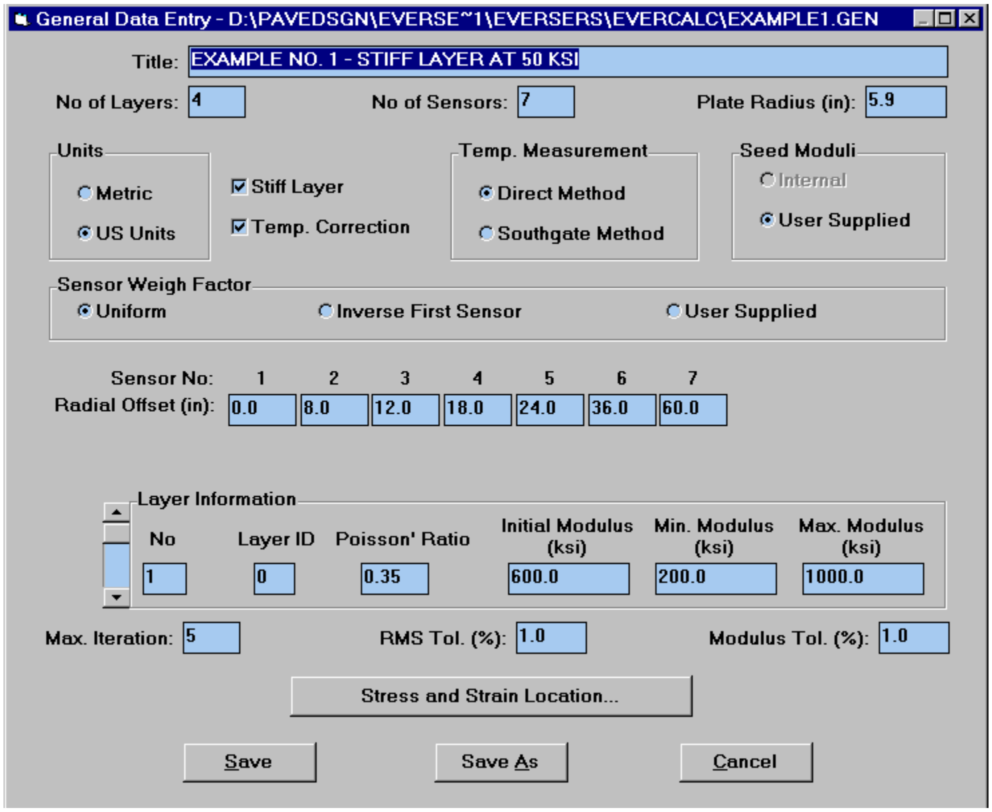


Figure 530.08.02.3 – Example General File – Stress & Strain Locations

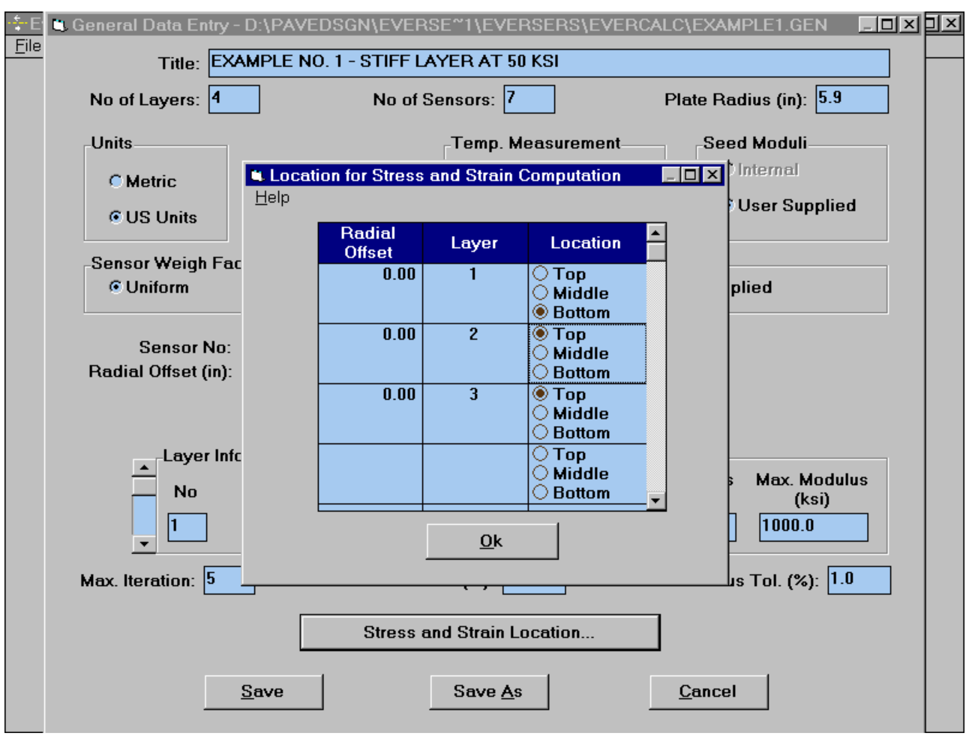


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Figure 530.08.02.4 – Example Deflection Data (.DEF) File

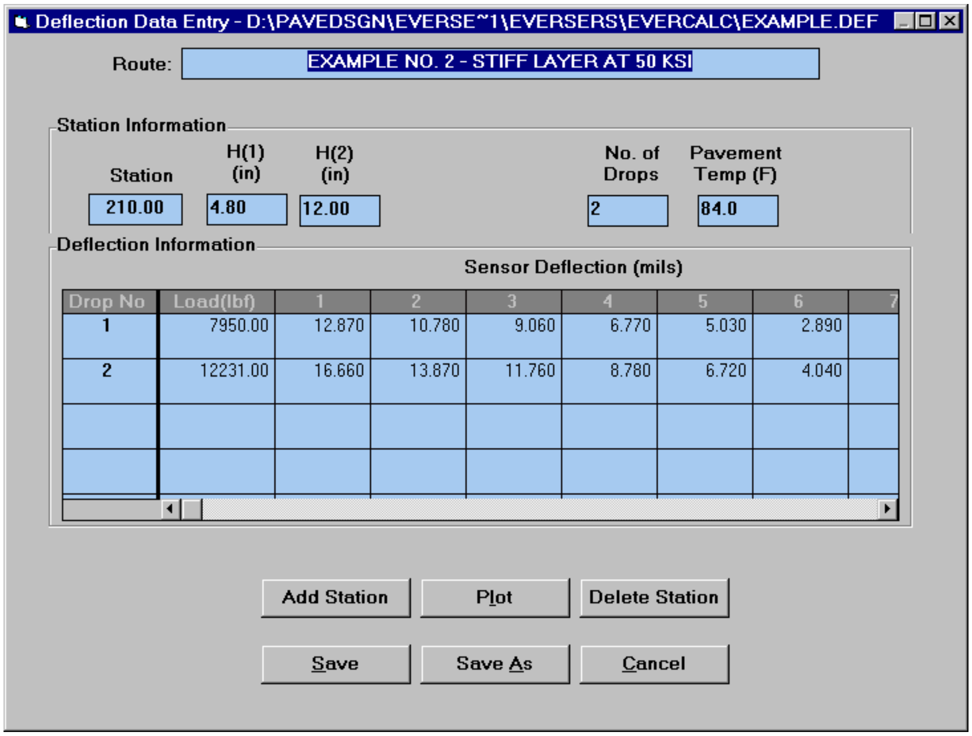

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Figure 530.08.02.5 – Example Detail Output for EVERCALC

```
Backcalculation by Evercalc 5.0 - Detail Output
Route: US20 Mp39 - 42  Stiff Layer @ 50ksi
Plate Radius (in):  5.9       No of Layers: 4
No of Sensors:  7      Stiff Layer: Yes
Offsets (in):     .0    8.0    12.0    18.0    24.0    36.0    60.0      P-Ratio: .350 .400 .450 .350
Station: 39              No of Drops:  2          Average RMS Error(%):   5.12
Thickness (in):     4.80    13.50   78.63         Pavement Temperature (F):  72.0
Drop No:  1    Load (lbf):    8787.0   No of Iterations: 3
Convergence: Modulus Tolerance Satisfied       RMS Error (%):  5.41
Sensor No:       1       2       3       4       5       6       7
Measured Deflections (mils):    19.370         14.950         11.670          8.700          6.720
         4.830          2.150
Calculated Deflection (mils):   19.097         13.962         11.541          9.087          7.330
         4.817          1.990
Difference (%):            1.41           6.61          1.11          -4.45          -9.08
.26        7.45
Layer No:        1       2       3       4      1-(adj)
Seed Moduli (ksi):       250.00          23.00          10.00          50.00         N/A
Calculated Moduli (ksi):        191.93          50.00          7.86          50.00          149.059
Layer No:        1       2       3       4
Radial Distance (in):     .00     .00     .00     .00
Position:        Bottom  Middle  Top     Top
Vertical Stress (psi):   -43.17          -14.31          -4.17          -.54
Radial Stress (psi):      53.17            4.18           -.30           .00
Bulk Stress (psi):        63.17           -5.95          -4.78          -.54
Deviator Stress (psi):   -96.33          -18.49          -3.87          -.54
Vertical Strain (10^-6):        -418.81         -353.14        -496.41         -10.82
Radial Strain (10^-6):   258.77          164.67         217.80          3.79
Drop No:  2    Load (lbf):   10706.0   No of Iterations: 2
Convergence: Modulus Tolerance Satisfied       RMS Error (%):  4.83
Sensor No:       1       2       3       4       5       6       7
Measured Deflections (mils):    23.150         17.950         14.130         10.690          8.370
         5.830          2.670
Calculated Deflection (mils):   22.815         16.942         14.073         11.107          8.973
         5.918          2.463
Difference (%):            1.45           5.62           .40           -3.91          -7.20
-1.51      7.75
Layer No:        1       2       3       4      1-(adj)
Seed Moduli (ksi):       191.93          50.00          7.86          50.00         N/A
Calculated Moduli (ksi):        217.23          50.00          7.75          50.00          168.709
Layer No:        1       2       3       4
Radial Distance (in):     .00     .00     .00     .00
Position:        Bottom  Middle  Top     Top
Vertical Stress (psi):   -50.48          -16.81          -4.93          -.65
Radial Stress (psi):      75.35            5.16           -.36           .00
Bulk Stress (psi):       100.22           -6.48          -5.65          -.65
Deviator Stress (psi):  -125.83          -21.98          -4.58          -.65
Vertical Strain (10^-6):        -475.17         -418.86        -595.23         -13.05
Radial Strain (10^-6):   306.79          196.46         261.16          4.56
Layer No:        1       2       3       4      1-(adj)
Mean Moduli (ksi):       204.58          50.00          7.80          50.00          158.88
Normalized Moduli (ksi):        194.74          50.00          7.85          50.00          151.240
K1 (ksi):       N/A     N/A     6.99     N/A
K2:     N/A     N/A     -.09     N/A
R-Squared:      N/A     N/A     100.00   N/A
Soil Type:      N/A     N/A     Fine     N/A
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Figure 530.08.02.6 − Example EVERCALC Output Summary

```
Backcalculation by Evercalc 5.0 - Summary Output
Route: US20 Mp39 - 42  Stiff Layer @ 50ksi
Plate Radius (in):  5.9    No of Layers: 4
No of Sensors:  7   Stiff Layer: Yes
Offsets (in): .0   8.0  12.0  18.0  24.0  36.0   60.0    P-Ratio: .350 .400 .450 .350
Station  Load (lbf) EAdj(ksi) E(1)(ksi) E(2)(ksi) E(3)(ksi) E(4)(ksi)    RMS Error
39         Thickness (in)  -      4.80     13.50    78.63    -     -
39        8787.0      149.1     191.9      50.0     7.9        50.0        5.41
39        10706.0     168.7     217.2      50.0     7.7        50.0        4.83
39          Norm.     151.2     194.7      50.0     7.8        50.0        5.12
40         Thickness (in)  -      4.80     13.50    56.39    -     -
40        8620.0      128.6     150.0      20.8     5.0        50.0       14.47
40        10666.0     128.6     150.0      22.2     5.0        50.0        9.97
40          Norm.     128.6     150.0      21.0     5.0        50.0       12.22
41         Thickness (in)  -      4.80     13.50    34.76    -     -
41        8839.0      420.1     442.5      26.4    25.0        50.0       17.52
41        11048.0     209.7     220.9      39.4    25.0        50.0       28.21
41          Norm.     404.8     426.4      27.3    25.0        50.0       22.86
42         Thickness (in)  -      4.80     13.50    16.38    -     -
42        8509.0      223.3     211.8      16.2    25.0        50.0       13.86
42        10889.0     221.5     210.2      18.1    25.0        50.0       10.57
42          Norm.     222.9     211.5      16.6    25.0        50.0       12.21
```

530.08.03 Rehabilitation Design Using EVERPAVE. EVERPAVE is a program developed by the Washington DOT and University of Washington. It is intended for the design of overlays to flexible pavements and can handle sections consisting of up to 4 layers plus subgrade. One of these layers may be the stiff layer. With appropriate modeling of the pavement section it can be used to design most rehabilitation alternatives. It uses the forward calculation method developed by the Corps of Engineers (WESLEA) to calculate deflections. Asphalt moduli input to the program must be temperature corrected to 77ºF (25ºC).

There are two versions of the program in use. Version 1.1 runs in MSDOS, but can be successfully run under WINDOWS 95 or NT with appropriate modifications to the system files. Version 5.0 is designed to run under WINDOWS 95 or NT.

Both versions utilize approximately the same input procedures. Version 1.1 allows only one shift factor for both existing and new asphalt. Version 5.0 allows different shift factors in the asphalt layers. The shift factor is used to shift the fatigue failure strain vs load repetition relationship to reflect the difference between laboratory fatigue tests and field performance.

Input to EVERPAVE is in three parts, a General Data File (.GEN or .G), a Pavement File (.PAV or .P) and Traffic Data. The General Data File contains information on the design wheel load, axle spacing, overly modulus, initial overlay thickness, analysis increment, seasonal reduction factors, seasonal temperatures, seasonal traffic and shift factor. An example of the General Data File for Version 1.1 is shown in 530.08.03.1. An example of the General Data File for Version 5.0 is shown in 530.08.03.2.

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The Pavement File contains the modulus, thickness and Poisson's ratio for each of the pavement layers. This file for version 1.1 is created from the MODULUS .DAT file by the ITD developed program NEWP. Since most of the design computations are made without considering stress dependency in the granular layers, the "Power" column is entered as zero. For version 5.0, the Pavement file data must be entered by hand until a data transfer program is developed. The Pavement Data File is binary. Therefore data entry and editing currently can only be performed in the program. An example of the Pavement Data File for Version 1.1 is shown in Figure 530.08.03.3. An example of the Pavement Data File for Version 5.0 is shown in Figure 530.08.03.4. The material type in Version 1.1 is designated by a number 1, 2, or 3: temperature dependent (asphalt), coarse granular and fine grained respectively. This has been expanded in Version 5.0 to include linear elastic or non-linear (stress dependent) options for base and subgrade.

In Version 1.1, traffic data is entered each time the program is run. Traffic data is entered into a separate file in Version 5.0. Examples of the Traffic Data are shown in Figures 530.08.03.5 and 530.08.03.6 for Versions 1.1 and 5.0 respectively.

Both programs are easy to follow. In Version 1.1 return to main menu after entering or calling up each data file. The output from Version 1.1 is a page for each station included in the Pavement Data File.

Some tips in using EVERPAVE:

- Correct the asphalt modulus to temperature 77ºF (25ºC) before creating the .pav file.

- Set shift factor at 4-5 for combination of old and new asphalt for overlay calculation. For new asphalt only use a shift factor of 10 –12.

- Initially set the stiff layer modulus to 50,000 psi (320 MPa). Often this value results in the lowest error. The presence of a water table is often shown in depth to stiff layer estimates. The above modulus will best handle a water table.

- For low modulus asphalt layers, it is advisable to change the material type for asphalt to granular material, and raise the shift factor to 10 –12. This simulates a granular material with a relatively high block modulus, which appears reasonable for pavements with extensive alligator cracking. The failure is then forced either to the overlay or to the subgrade. It provides a check on the probable minimum required overlay. In Version 5.0, different shift factors are applied to the various asphalt layers, but the same procedure can be used.

- For the design of inlays or hot, in-place recycling, build the pavement section using the in-place layer properties, but leaving out the material to be milled off or recycled. The thickness of the overlay calculated by the program will include the inlay or recycled material.

- In CRABS design, replace the existing section that will be pulverized and recompacted with the design thickness of CRABS at the recommended modulus and Poisson's ratio. The material remaining below the CRABS should be input with the back-calculated properties developed from deflection testing (remaining base, subbase and subgrade). The calculated overlay will be the thickness of new surfacing needed. Use the minimum thickness for the proposed aggregate size as the initial thickness to speed up the process.

- A similar procedure can be used for cold, in-place recycling.

Figure 530.08.03.1 – Example General Data Input Screen – EVERPAVE 1.1

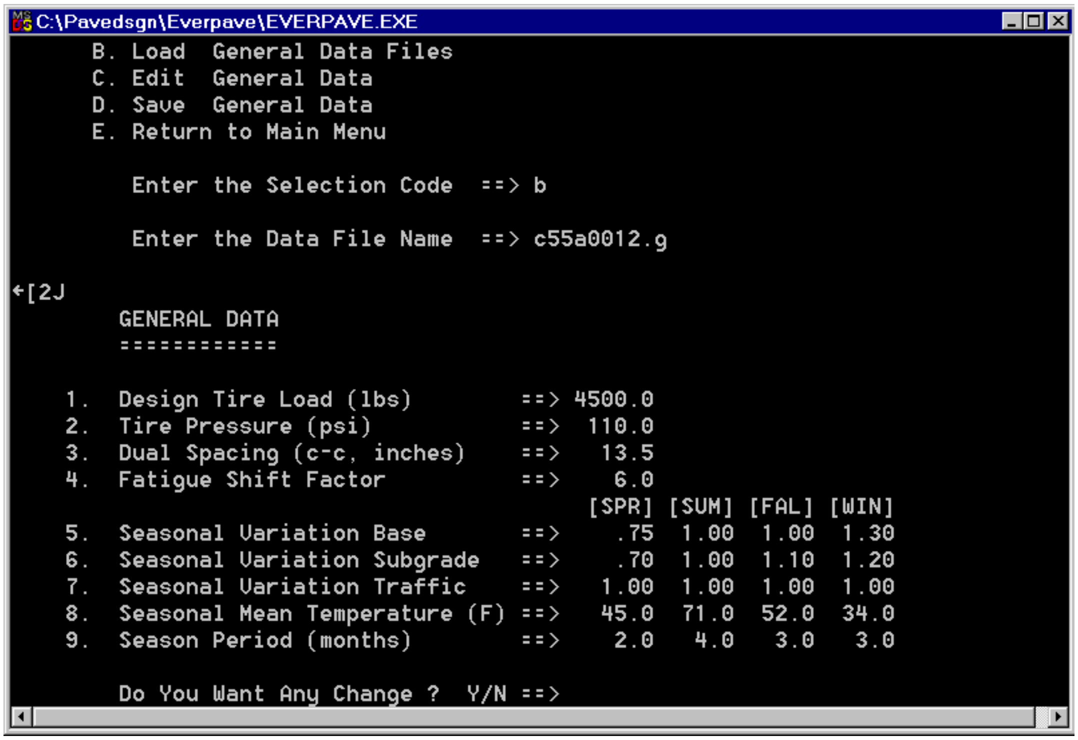

Figure 530.08.03.2 – Example General Data Input Screen – EVERPAVE 5.0

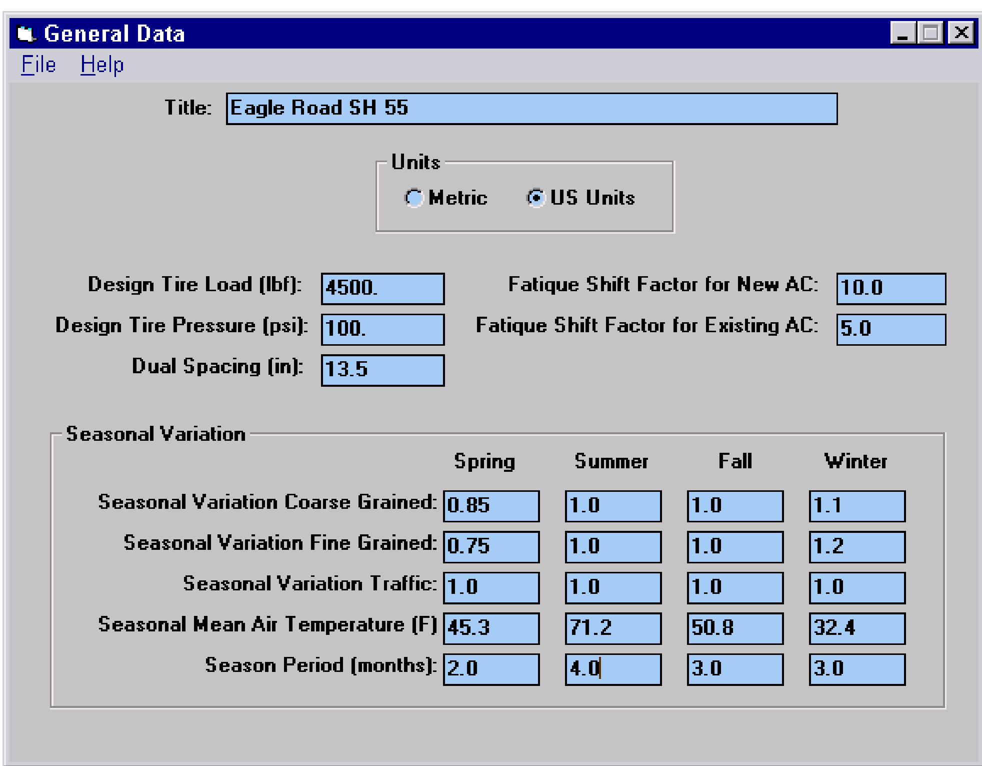

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Figure 530.08.03.3 – Example Pavement Data Input Screen – EVERPAVE 1.1

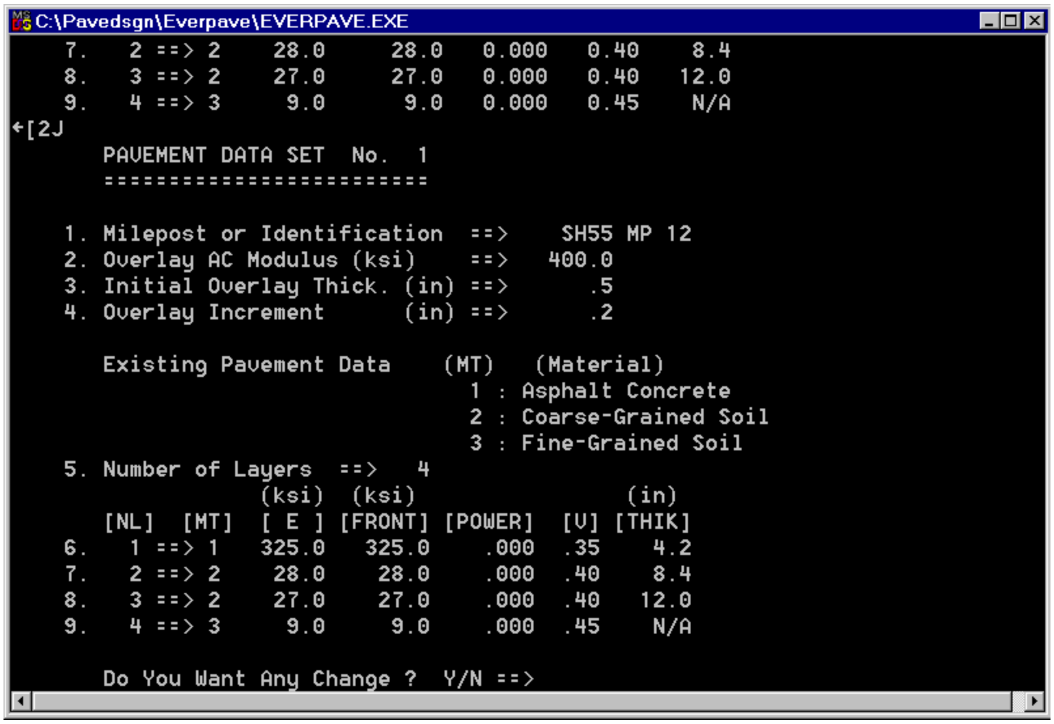

Figure 530.08.03.4 – Example Pavement Data Input Screen – EVERPAVE 5.0

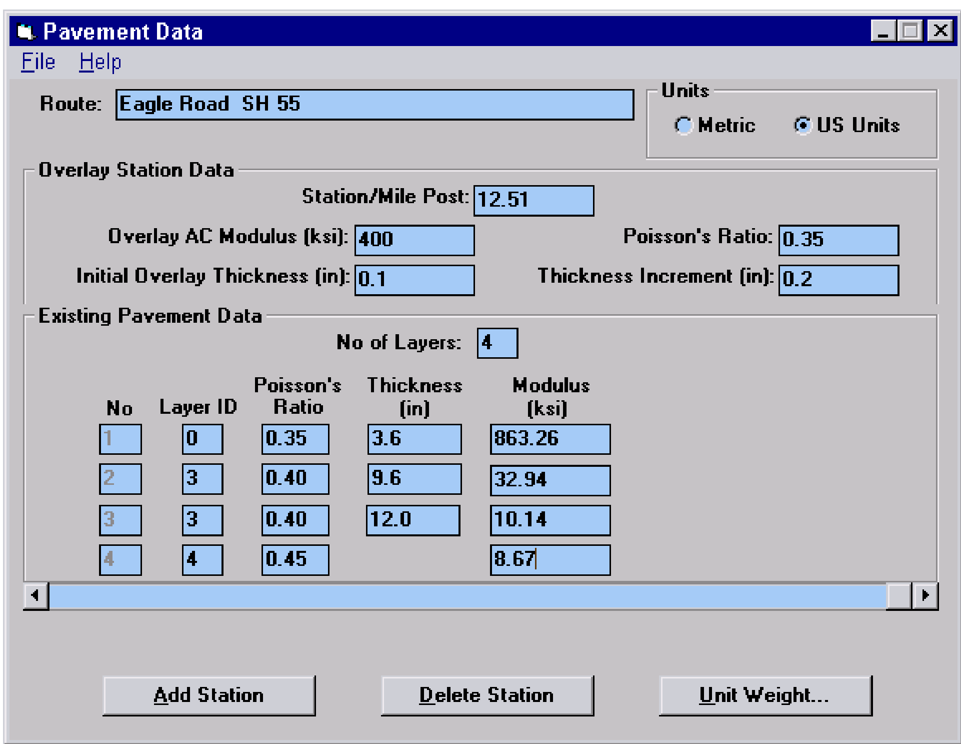

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Figure 530.08.03.5 – Example Traffic Data Input Screen – EVERPAVE 1.1

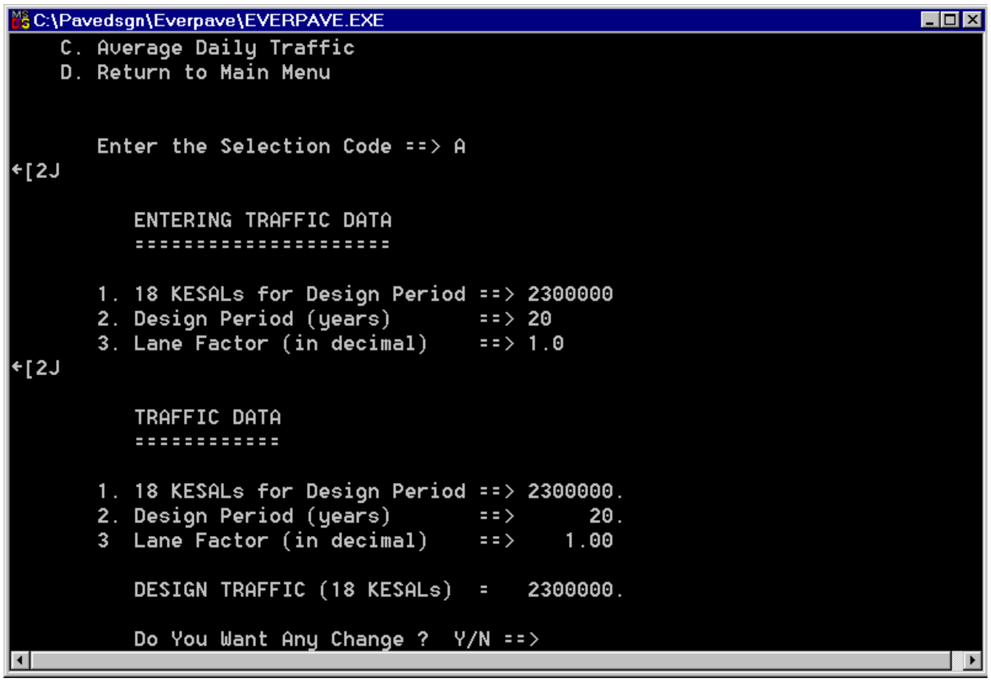
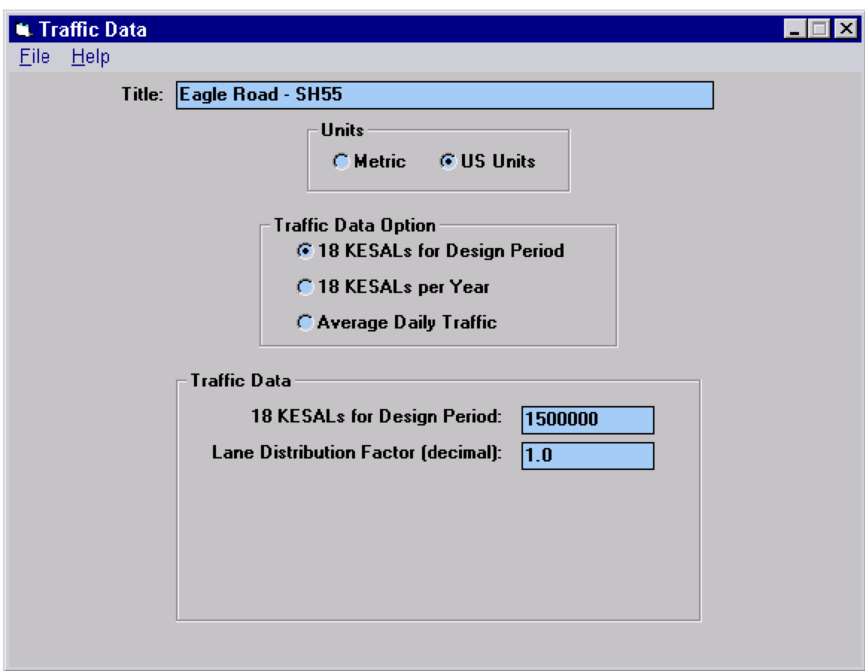


Figure 530.08.03.6 – Example Traffic Data Input Screen – EVERPAVE 5.0



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Suggested default values for the EVERPAVE .G or.GEN file are as follows:

Wheel Load 4500 lb. (20,000 N)
Dual Spacing 12.5 to 13.5 in. (32 – 34 cm)
Tire Pressure 110-120 psi (758 – 827 kPa)
Shift Factor: 4-5 for combination of old pavement and overlay in EVERPAVE 1.1; In EVERPAVE 5.0 assign the shift factor for the existing pavement based on remaining fatigue life. Probable values range from 2-6. New pavement in both programs should have a shift factor of 10-12. Existing pavement with extensive fatigue cracking should be treated like an aggregate base with a block modulus, and the shift factor will only apply to the new asphalt.

Seasonal Temperature: Calculate from NOAA average temperature data for the nearest weather station(s). Input temperatures are seasonal averages. Volume 13 of the NOAA Climatic Data contains average monthly temperatures for the year and departures from normal. From these the normal long-term average monthly temperatures can be calculated. Monthly average temperatures are also available for each weather station from the Internet.

Seasonal Months: Most areas will have four three month-long seasons. Locally, the seasons may not be equal in length; winter may be 4 months long in colder areas. Typical seasons are Dec-Feb, Mar-May, June-Aug. and Sept.-Nov.

Seasonal Modulus Adjustment: This value is local climate and subgrade soil dependent. The critical spring thaw period is usually two weeks to a month and base and subgrade moduli may be reduced by as much as half during that period. EVERPAVE groups seasonal modulus reductions over the number of months assigned as Spring. Without more accurate data, use 0.75 for subgrade and 0.8 for base (assuming summer as 1.0). During the period when the pavement section is frozen, use 1.10 – 2.0. Fall values will usually be 1.0, unless Fall rains produce a wetter than normal subgrade. A slight reduction may then be appropriate. The climatic period in which the deflection measurements are taken should be assigned a reduction factor of 1.0. Other seasons will be relative to that. For assistance call Headquarters Materials.

Seasonal Traffic: Unless there is a definite variation in truck traffic between seasons, use 1.0 for each season. If the traffic varies, the sum of the coefficients for all four seasons must be 4.0.

Suggested default values in the EVERPAVE .P or .PAV file are as follows:

Overlay Modulus: Use 380 – 400 ksi at 77ºF (2620 – 2760 MPa at 25ºC)

Initial Overlay Thickness: Use a nominal value such as 0.01 inches (0.02 cm) In many cases the programs will not accept a zero initial thickness. Where the new surface will be at least a minimum thickness, such as in CRABS or Hot recycle, use that minimum value as an initial thickness. Where design pavement life is shorter than 20 years, estimate the actual overlay needed to determine probable pavement life. Regardless of design life, run a 20 year design for information.

Overlay Increment: Suggest 0.2 inches (0.5 cm)

Material Type: In Version 1.1 these are typically 1 for existing asphalt (temperature dependent), 2 for coarse grained materials (base, subbase, gravel subgrade) and 3 for fine grained materials (typical subgrade) Crabs and severely cracked existing asphalt should be treated as a coarse grained material (2). In Version 5.0, use 0 for existing asphalt, and for stress insensitive analysis use 3 for coarse grained and 4 for fine grained materials.

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Designation 5 may be used where material such as badly fatigued old asphalt or CRABS is neither stress nor temperature sensitive. This version allows input of a stiff layer modulus where hard material or rock is close to the surface. When a stress insensitive analysis is chosen, the Multiplier and Power columns will disappear. If stress sensitive analysis is desired, call Headquarters materials for assistance.

Front and Power: In Version 1.1, The Front value should be the same as the modulus for each layer for linear elastic analysis, and the Power is zero.

Poisson's Ratio: Typical values are 0.35 for asphalt, 0.4 for aggregate base and subbase, and 0.45 for fine grained subgrade. CTB can be assumed at 0.3 if intact. CRABS should be given a value of 0.4.

Modulus: For asphalt surface, base layers and subgrade use the values from the MODULUS or EVERCALC programs. Remember to correct the asphalt modulus back to 77ºF (25ºC). EVERCALC output moduli are corrected to 77ºF (25ºC) in the program. Current data suggests a modulus for CRABS at a maximum of 210 ksi. (1450 mPa). Where thinner asphalt layers or deteriorated base materials are incorporated into CRABS, lower moduli should be expected.

Data from Mountain Home indicates a typical modulus for cracked and seated concrete is 1,000 ksi (6895 MPa). Limited data is available for cold-in-place recycled asphalt (CIR). From these data, we suggest a modulus approximately the same as CRABS, except that the CIR is temperature dependent. The modulus-temperature relationship has not been developed at this point, so the typical hot-mix asphalt relationship should be used until better data is available.

New base and subbase materials will typically range from 35 to 70 ksi (240 to 480 MPa). Subgrade moduli from MODULUS or EVERCALC should not be reduced to reflect laboratory values.

Thickness: Input thickness of layers in inches (cm). When batch processing in Version 1.1, the same thicknesses are out put for all points by the NEWP program. Changing thicknesses to reflect exploration data will require editing the .P file. In the current Version 5.0, the pavement data must be entered manually for each test location.

Traffic data is input in a separate file. Three choices are available: Total ESALs for the design period, Average Daily Traffic and Average Annual ESALs. In the first option, if input ESALs are already reduced to the design lane, use a lane factor of 1. The program uses ESALs in the design lane, so if, for instance, total ESALs in one direction are input for a four lane interstate highway, the lane factor might be 0.8 if 80% of the ESALs are in the design lane. The other options require additional information such as growth factor. The traffic data from Planning provides estimates of total ESALs, directional ESALs and ESALs in the design lane. Examples of the Traffic data input for EVERPAVE 1.1 and 5.0 are shown in Figures 530.08.03.5 and 530.08.03.6 respectively.

Output from both EVERPAVE 1.1 and 5.0 is an .OUT file. Each station analyzed requires one page of output data. An example page for Version 5.0 is shown in Figure 530.08.03.7. The output file for Version 1.1 is similar. A summary containing only the test location, input moduli, layer thicknesses, damage factors and calculated overlay thicknesses along with the general data input can be developed for EVERPAVE 1.1 in both an EXCEL spread sheet and a text file using the program EPAVECSV. An example of the summary for Version 1.1 is shown in Figure 530.08.03.8. Minor changes will be needed to summarize out put from Version 5.0.

Note: *Analysis and design computations are currently performed in English Units and the final design thicknesses converted to metric units.*

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Figure 530.08.03.7 − Example Output from EVERPAVE 5.0

```
CLayered Elastic Analysis by Everpave for Windows

General Data:  Eagle Road Fairview to I 84
Design Tire Load (lbf):  4500.0
Tire Pressure (psi): 110.00    Dual Spacing (in): 13.5
Fatigue Shift Factor:  New AC:10.00    Old AC:    6.00

#Seasonal Variation:     Spring  Summer  Fall    Winter
#Coarse Grained:           .750   1.000   1.000   1.300
#Fine Grained:     .700    .900   1.100   1.200
#Traffic Volume:          1.000   1.000   1.000   1.000
#Mean Air Temp. (F):       45.0    71.0    52.0    34.0
#Period (month):            2.0     4.0     3.0     3.0

Traffic Data:  16-530 epave5
 18 KESALs for Design Period :  1500000.
Lane Distribution Factor (decimal) : 1.00
Total Design Traffic (18 KESALs) :  1500000.

Route:  Eagle Road
Station: 12.43
Layer   Poisson's Thickness    Moduli
*       Ratio      (in)        (ksi)
1        .35       .100       400.00
2        .35      3.600       936.23
3        .40      9.600        20.11
4        .40     12.000        40.32
5        .45       *           10.69

cPavement Moduli Used (ksi)

Layer   Material Spring      Summer       Fall        Winter

1       A.C      1190.14     327.48       888.13      1737.76
2       A.C      2785.61     766.49      2078.73      4067.36
3       C.G        15.08      20.11        20.11        26.14
4       C.G        30.24      40.32        40.32        52.42
5       F.G         7.48       9.62        11.76        12.83

cCritical Values

#Season:                          Spring   Summer    Fall     Winter

#Tensile Strain in New AC:        -16.17   -24.39   -15.92    -10.29
#Tensile Strain in Old AC:         71.29   163.25    81.15     46.76
#Compressive Strain in Subgrade:     .00      .00      .00       .00
#Max. Surface Deflection (mils):  14.53    15.51    11.34      8.76

cDamage Levels
Fatigue Damage on New A.C:  .000
Fatigue Damage on Old A.C:  .931
Rutting Damage on Subgrade: .000

Overlay Thickness (in):  2.30
```

Figure 530.08.03.8 − Example CSV Summary of EVERPAVE 1.1 Output

C55A0012.csv OVERLAY DESIGN SUMMARY EverPave 1.1

PROJECT: SH055 MILEPOST 12.4-12.7 PROJ. # 16-530 csv 000(DATE: 5/5/98

GENERAL DATA:

Design Traffic Data:		
18 Kip ESALs:	1500000	
Design Period (yrs	20	
Shift Factor		6
Overlay AC Modulus (ksi)		400
Initial Overlay Thickness (in)		0
Overlay Increment (in)		0.2

Seasonal Variatio	(SPR)	(SUM)	(FAL)	(WIN)
Granular Base:	0.75	1	1	1.3
Subgrade:	0.7	1	1.1	1.2
Traffic Volume Ra	1	1	1	1
Period (month)	2	4	3	3
Mean Air Temp. (I	45	71	52	34

	Asphalt Concrete		Base		Subbase		Subgrac	Damage Levels			Overlay
Milepost	E (ksi)	THK (in)	E (ksi)	THK (in)	E (ksi)	THK (in)	E (ksi)	New AC	Old AC	Subgrade	(in)
12.4	936.2	3.6	20.1	9.6	40.3	12	10.7	0	0.95	0.02	1.6
12.4	915.4	3.6	23.8	9.6	29.2	12	11.5	0	0.92	0.02	1.6
12.5	578.3	3.6	35.1	9.6	10.5	12	12.1	0	0.93	0.01	2.1
12.5	926.2	3.6	22.2	9.6	23.5	12	8.8	0	0.91	0.04	1.8
12.5	863.3	3.6	32.9	9.6	10.1	12	8.7	0	0.91	0.04	1.8
12.5	795.9	3.6	23.5	9.6	24.7	12	8.5	0	0.94	0.04	1.9
12.5	911.2	3.6	19.5	9.6	21.4	12	8	0	0.97	0.05	1.9
12.6	922.1	3.6	32.6	9.6	11.2	12	9.1	0	0.96	0.04	1.6
12.6	803.7	3.6	26.1	9.6	28.1	12	9	0	0.89	0.03	1.8
12.6	816.9	3.6	23.2	9.6	25.2	12	8.5	0	0.92	0.04	1.9
12.6	891.4	3.6	29.7	9.6	10.2	12	8.7	0	0.96	0.04	1.8
12.6	728.5	3.6	26.5	9.6	23.6	12	7.8	0	0.95	0.05	1.9
12.7	882.8	3.6	26.5	9.6	9.4	12	8	0	0.88	0.04	2.1
12.7	825.6	3.6	17.2	9.6	19.9	12	8.1	0	0.95	0.04	2.2
12.7	803	3.6	35.1	9.6	10.9	12	8.1	0	0.91	0.05	1.8
12.7	1600	3.6	16.7	9.6	10.6	12	14	0	0.89	0.01	1.4
12.7	1007.8	3.6	31.1	9.6	15.1	12	10.1	0	0.97	0.03	1.4
12.7	825.4	3.6	22.3	9.6	38.9	12	10.8	0	0.87	0.02	1.8
12.7	834.5	3.6	19.2	9.6	60	12	9.8	0	0.88	0.01	1.8
12.7	685.8	3.6	27.5	9.6	35.8	12	9.9	0	0.91	0.02	1.8

Avg.	1.8
St. Dev.	0.20774
90th %	2.06591

530.08.04 Rehabilitation Design Using WINFLEX. WINFLEX is a mechanistic, deflection based design program developed by the University of Idaho. It will either analyze single locations or a multiple location file, and is designed to run in WINDOWS 2000 or NT. Instructions for operating the program are contained in the WINFLEX User's Manual, which is contained on the CD ROM. Input data is further discussed below.

When opening the program, the user has the opportunity to choose Metric or English units. The next screen gives the option of creating a new input file or loading a pre-existing file. On choosing new file, the choice between multiple and single locations is requested. Nearly all of the ITD projects will require multiple locations (batch loading). Multiple locations will require the layer modulus data in an .ETF file before the input file (.INP) can be developed. The .ETF file should be developed using the program ETF6.exe from the MODULUS .DAT file independent from the WINFLEX program. Once the .ETF file is loaded, input can continue. Loading an existing file presumes that an .ETF file exists. If existing Input files are to be used with new .ETF files, these should be developed prior to entering the Program.

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WINFLEX adjusts the asphalt modulus for temperatures in each of four seasons. In addition the input asphalt modulus is temperature corrected by the default temperature-modulus correlation (SHRP) or by a user input correlation. Additional temperature-modulus correlations may be developed and saved within the program. **Correcting the moduli for field temperature prior to running the program is not required.**

Seasonal temperature and modulus adjustment factors may be input, or default values for six different climatic zones may be used. These default values are based on data from climate indices such as Thornthwaite Moisture Index and Freezing Index, air temperature and precipitation. These defaults are suitable if no other data is available. However, user defined values are considered more suitable until additional work is performed to increase the number of climatic zones. Suggested seasonal adjustment factors are presented in Section 530.08.03. If shorter spring seasons are used, a lower adjustment factor may be appropriate. Similar to the temperature-modulus correction, additional seasonal adjustment factors for new zones may be created and saved in the program. To utilize user defined climatic adjustment factors. Select “Other” in the list of climatic zones. This will allow editing of the factors existing in the cells ore clear them to enter new data. The newly entered values can be saved under a separate Zone name with the .ZON extension. To load a Zone from the file, press “Other” and load. Season lengths must add up to 12. Relative seasonal traffic variation numbers need not add up to 4. Typically seasonal adjustment factors are relative to the season when field data was collected. That season is assigned an adjustment factor of 1.0.

Suggested input data default values for the WINFLEX program are essentially the same as presented in Section 530.08.03. In the General Data File, use a 4500 lb (40 kN) axle load, and a dual wheel spacing of 12.5 to 13.5” (317 to 342 mm). The analysis methods are based on 80 psi (550 kPa) tire pressure. Tire pressures have increased through the years. It is not strictly correct, however we suggest tire pressures of 100 to 110 psi (700 to 760 kPa) be used.

WINFLEX has a provision for selecting the failure model to be used in the design computations. It allows selecting either fatigue failure or rutting in the subgrade or both. In addition the user can select between nine fatigue models and six rutting models. For project applications, the Asphalt Institute models are recommended for both fatigue and rutting. The Shell Research fatigue model has been chosen for use in the AASHTO 2002 Pavement Design Guide, and may be a good candidate for comparison analysis. <u>Until the applicability of the other models contained in the program has been determined, the Asphalt Institute models will considered the standard for project level work.</u>

Shift factors for the Asphalt Institute fatigue model selected for new and old asphalt should range from 4 to 12, as discussed in Sections 530.08 and 530.08.03. A Shift Factor of 1 is appropriate for the Shell model, since it is supposed to be correlated with field performance. If assistance is needed in developing the appropriate shift factors, call Headquarters Materials.

The traffic data to be entered into the .INP file is the total number of ESALs in the design lane over the design life of the project. When entering ESALs, do not include commas (e.g. 2million should be entered 2000000 or 2E6 not 2,000,000). The program will read the comma as a decimal point.

In the pavement data file, the number of layers option is shown as a choice of full depth asphalt, asphalt surface and base, or asphalt surface, base and subbase. An overlay modulus of 400 ksi at 77ºF (25ºC), a Poisson’s ratio of 0.35 and an initial thickness greater than 0 are appropriate for WINFLEX. The overlay increment used will depend on the precision desired (0.2 in. is suggested). The temperatures, moduli, Poisson’s ratios and thicknesses of the pavement layers may be input here for a single location or will be provided in an ETF file for batch processing.

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Additional options in WINFLEX include: an option to treat the existing asphalt as a granular material and a choice of failure modes. Where the asphalt surface modulus is very low at 77ºF (25ºC), and fatigue cracking is evident over a large percentage of the project, choosing to treat asphalt as gravel will eliminate fatigue failure in the existing surfacing. This option requires a fixed modulus be input for the asphalt layer. This same option can be used for CRABS design by writing in the CRABS modulus. The minimum modulus which can be entered is 50ksi.

After entering pavement data, clicking next will bring up the Material Types screen. This is where the material analysis models are input. For stress independent (linear) aggregate base analysis choose GRAN(LINEAR) Cement Treated and Bituminous Treated base options are also available. With the GRAN(LINEAR) and CEMENT T.B. options, the K1 and K2 stress dependency parameters disappear. With the BITUMEN T.B. option, asphalt % by volume (Vb) and % air voids (Va) are needed. The GRANULAR option is stress dependent, requiring the stress dependency parameters. Call Headquarters Materials for assistance. The only subbase options are GRANULAR (stress dependent) and GRAN(LINEAR).

Choose GRAN(LINEAR) for most analyses. Subgrade options include FINE and GRANULAR (both stress dependent) and LINEAR (stress independent). For most analyses, choose LINEAR.

In summary, the input data is entered in the following sequence: Pavement Data, Material Types, Models Selection, General Data and Temperature Correction model selection screens. Once entered, these data are all saved in an .INP file. Examples of the input screens are shown in Figures 530.08.04.1, through 530.08.04.5.

The Pavement Data, shown in Figure 530.08.04.1, is for a batch load or multiple location analysis. Moduli, temperatures and thicknesses are contained in the .ETF file.

530.08.04.1 – Example – WINFLEX Pavement Data Input Screen

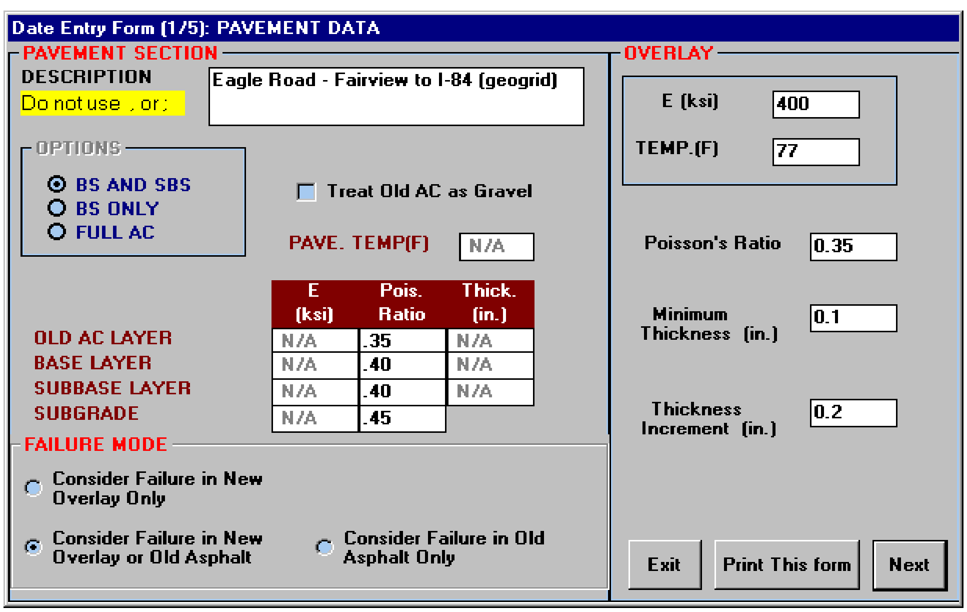

Figure 530.08.04.2 − Example – WINFLEX Material Types Input Screen

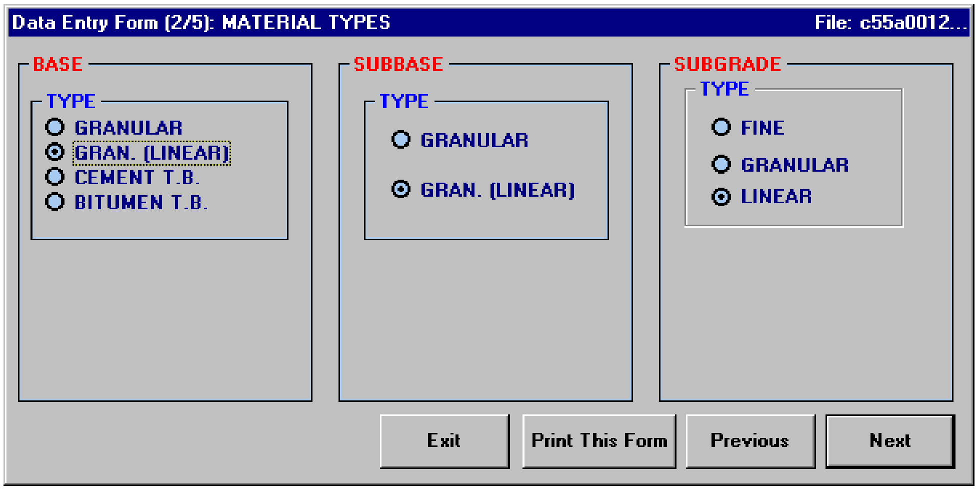

Figure 530.08.04.3 − Example – WINFLEX Failure Models Input Screen

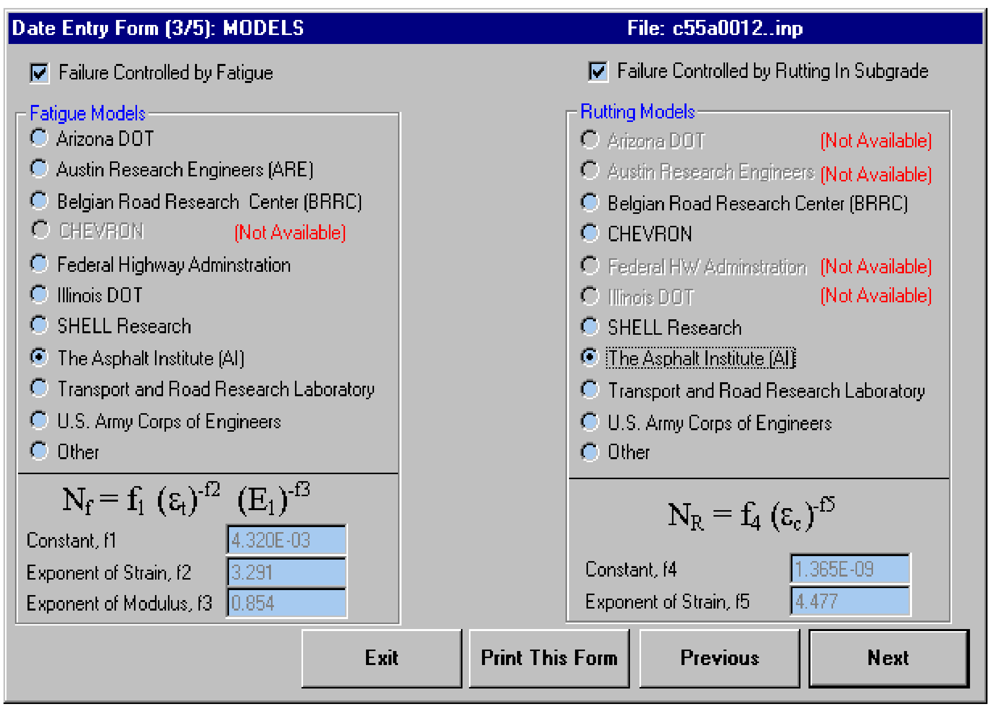

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Figure 530.08.04.4 – Example – WINFLEX General Data Input Screen

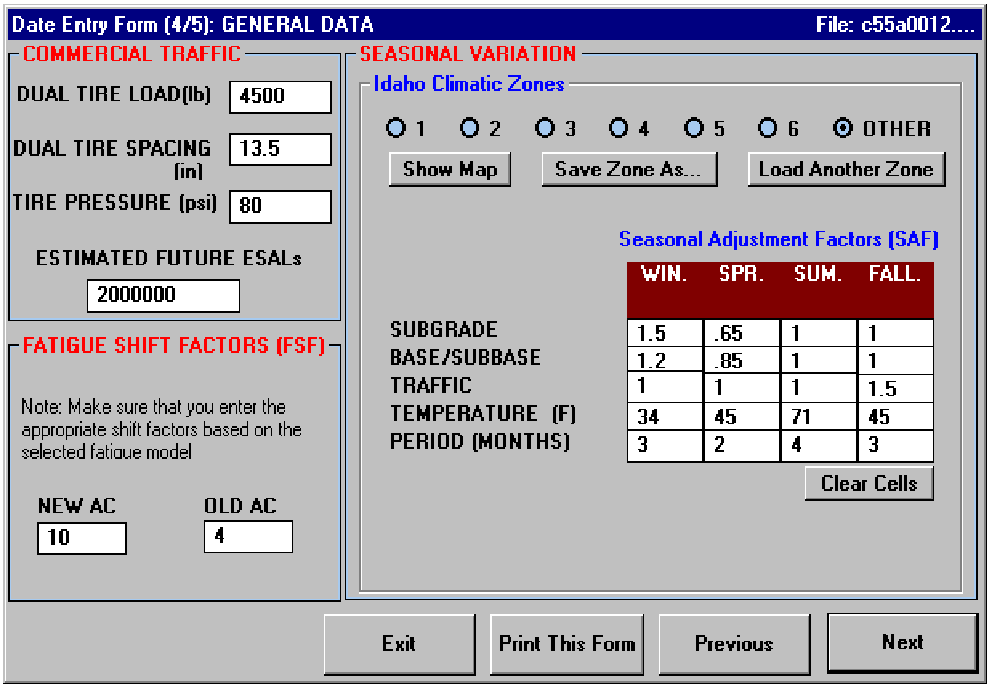
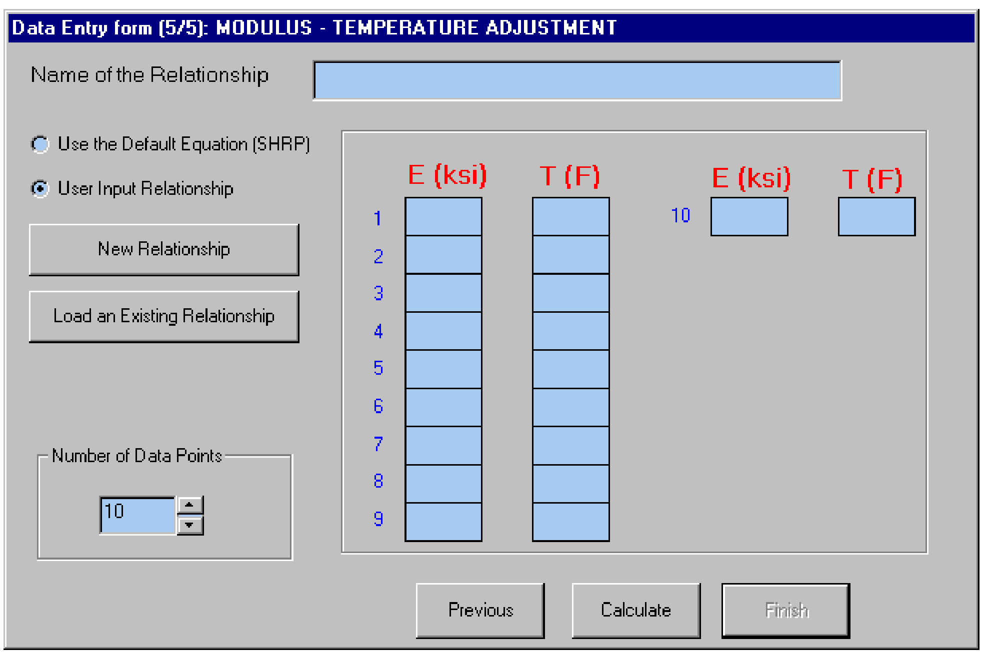


Figure 530.08.04.5 – Example – Modulus-Temperature Adjustment Screen



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The calculated overlays are displayed as shown in Figure 530.08.04.6 automatically following the calculation process. This screen also shows the output options. The results of a multiple locations analysis are collected and can be saved in a file with an .FLX extension. The summary of results can also be viewed as an Excel spread sheet and printed. Figure 530.08.04.6 shows the calculated strains displayed with the show strains option.

The output file or .FLX file is shown as an EXCEL spread sheet in Figure 530.08.04.7. The format has been altered to contain the file on one page. The station, temperature, modulus and thickness data in the spreadsheet is the information contained in the .ETF file input for multiple location analysis.

Figure 530.08.04.6 − Example – WINFLEX Output Options Screen

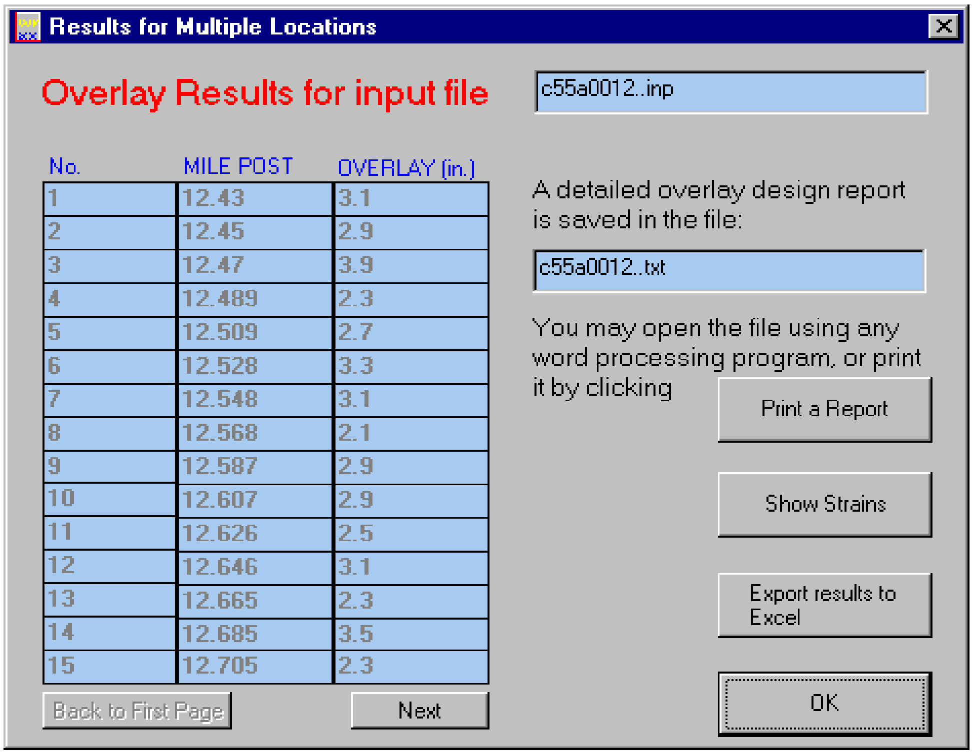

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Figure 530.08.04.7 – Example – WINFLEX Strain Data Output Screen

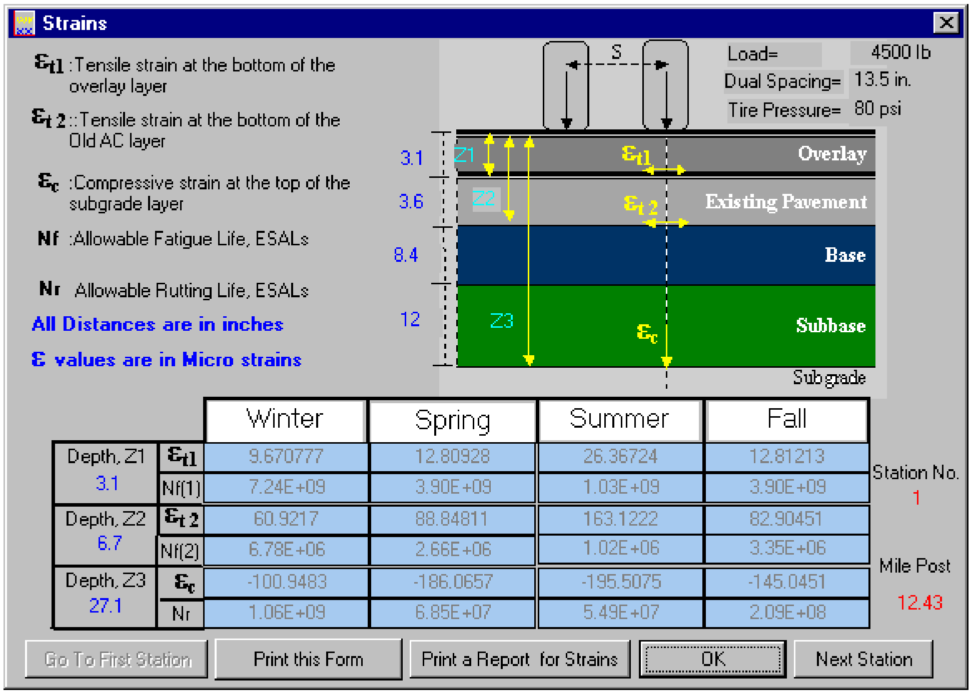

Figure 530.08.04.8 − Example – WINFLEX Output – Multiple Location Analysis

ETF FILE : C:\PAVEDSGN\Winflex\C55a0012.etf
THIS FILE SHOULD BE RUN WITH C55a0012.inp

CASE	MILE POST	TEMPERATURE	E1	E2	E3	E4	OVERLAY	DAMA1	DAMA2	DAMA3	DAMA4	DAMA22	H1	H2	H3
1	12.43	53	936.225	20.114	40.322	10.692	1.91	0	0.9441	0	0.0333	0	3.6	9.6	12
2	12.45	53	915.365	23.808	29.222	11.47	1.91	0	0.9221	0	0.0347	0	3.6	9.6	12
3	12.47	54	578.295	35.079	10.473	12.06	3.01	0.0011	0.9115	0	0.0174	0	3.6	9.6	12
4	12.489	56	926.216	22.176	23.518	8.783	2.11	0	0.9213	0	0.0695	0	3.6	9.6	12
5	12.509	56	863.256	32.937	10.139	8.67	2.11	0	0.9251	0	0.0692	0	3.6	9.6	12
6	12.528	56	995.929	23.498	24.737	8.469	2.31	0	0.9974	0	0.068	0	3.6	9.6	12
7	12.548	57	911.202	19.463	21.443	7.995	2.31	0	0.957	0	0.0874	0	3.6	9.6	12
8	15.68	57	922.074	32.558	11.201	9.081	1.81	0	0.9743	0	0.0716	0	3.6	9.6	12
9	12.587	58	803.714	26.142	28.147	8.97	2.11	0	0.9726	0	0.057	0	3.6	9.6	12
10	12.607	59	816.919	23.197	25.166	8.495	2.31	0	0.96	0	0.0664	0	3.6	9.6	12
11	12.626	59	891.412	29.698	10.204	8.664	2.11	0	0.9669	0	0.0744	0	3.6	9.6	12
12	12.646	59	728.553	26.484	23.578	7.795	2.61	0	0.8923	0	0.0698	0	3.6	9.6	12
13	12.665	59	882.811	26.45	19.425	8.014	2.31	0	0.9948	0	0.0889	0	3.6	9.6	12
14	12.685	59	825.593	17.173	19.846	8.126	2.81	0	0.9254	0	0.0716	0	3.6	9.6	12
15	12.705	62	803.028	35.082	10.888	8.106	2.11	0	0.9627	0	0.0826	0	3.6	9.6	12
16	12.7401	60	1599.996	16.671	10.561	13.959	0.91	0.0027	0.9864	0	0.0301	0	3.6	9.6	12
17	12.7401	59	1007.807	31.093	15.076	10.08	1.61	0.0001	0.9058	0	0.0598	0	3.6	9.6	12
18	12.7401	60	825.521	22.25	38.896	10.82	2.11	0	0.9638	0	0.0307	0	3.6	9.6	12
19	12.7401	60	834.519	29.21	59.999	9.83	2.11	0	0.9766	0	0.0248	0	3.6	9.6	12
20	12.7401	61	685.836	27.547	35.754	9.936	2.31	0.0002	0.9931	0	0.0346	0	3.6	9.6	12

DAMA1 = FATIGUE DAMAGE ON OVERLAY DAMA2 = FATIGUE DAMAGE ON OLD AC DAMA3 = FATIGUE DAMAGE ON BTB
DAMA4 = RUTTING DAMAGE DAMA22 = FATIGUE DAMAGE DUE TO PAST TRAFFIC
The fatigue model used was 'Asphalt Institute'
The Rutting model used was 'Asphalt Institute'

530.08.05 AASHTO Design Guide. Overlay design using the 1993 AASHTO Design Guide (DARWin) can provide a design check of the results using EVERPAVE or WINFLEX. See the 1993 AASHTO Guide For Design of Pavement Structures for guidance in using the DARWin program.

The AASHTO method has some advantages including the ability to account for drainage and reliability of the input data, and allows input of the subgrade modulus at two-week intervals.

There are some major drawbacks. The design equations are based on the data from the original AASHTO Test Road in Illinois and represent the subgrade at that site. The pavement section is combined into a composite modulus, eliminating the ability to analyze the effect of individual layers. The dependence on structural numbers is more empirical than mechanistic. The subgrade modulus from back calculation of FWD data must be modified by a correction factor to match laboratory results that were the basis of the equations from the AASHTO Test Road. Generally we find that the asphalt overlay thickness is larger than with other methods. The current AASHTO design method will be phased out as the more mechanistic AASHTO 2002 program is implemented.

The currently recommended design methods using EVERPAVE or WINFLEX more closely fit the requirement for a mechanistic design method as required by an agreement with FHWA in a pavement initiatives review in 1990.